IMPACT OF AIR POLLUTANTS ON AGRICULTURE PRODUCTIVITY

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON NATURAL RESOURCES,
AGRICULTURE RESEARCH AND ENVIRONMENT

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY

AND THE

SUBCOMMITTEE ON DEPARTMENT OPERATIONS,
RESEARCH, AND FOREIGN AGRICULTURE

OF THE

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IMPACT OF AIR POLLUTANTS ON AGRICULTURE PRODUCTIVITY

THURSDAY, JULY 9, 1981

House of Representatives, Committee on Science and Technology, Subcommittee on Natural Resources, Agriculture Research and Environment; Committee on Agriculture, Subcommittee on Department Operations, Research, and Foreign Agriculture,
Washington, D.C.

The committees met in joint session, pursuant to notice, in room 2318, Rayburn House Office Building, commencing at 9:23 a.m., Hon. George E. Brown, Jr., presiding.

Present: Representatives Brown of California, Fuqua, Scheuer, Carney, Schneider, Gregg, Sensenbrenner, and Roberts of Kansas.

Mr. **Scheuer** [presiding]. Today we continue the joint hearings between the two subcommittees, the Natural Resources Subcommittee of the Science and Technology Committee, and the Agriculture Subcommittee on Department Operations, Research, and Foreign Agriculture.

I am very sorry that my colleague, George Brown, who is chairing these meetings with me, has been delayed. His office tells us he is tied up in traffic. But since it is now almost 9:25, I thought we probably should get started.

Here he is.

Mr. **Brown** [presiding]. Let me apologize for the delay, and in the event I have an opening statement, it will be inserted in the record at this point.

[The opening statement of Mr. Brown follows:]

OPENING STATEMENT
HONORABLE GEORGE E. BROWN, JR.
CHAIRMAN, SUBCOMMITTEE ON
DEPARTMENT OPERATIONS, RESEARCH, AND FOREIGN AGRICULTURE
THE IMPACT OF AIR POLLUTANTS ON AGRICULTURAL PRODUCTIVITY
JULY 9, 1981

Today's hearings are a follow-up to joint hearings held in 1979 on Agricultural productivity and environmental relationships. At that time, Subcommittees of the Agriculture Committee and the Science and Technology Committee examined a wide range of environmental issues involving agriculture including the subject of today's hearing, the effect of air pollution on America's agricultural and forestry production.

Since that time, research on this issue has been funded and conducted by a number of government agencies and public and private institutions. The Environmental Protection Agency, the Department of Agriculture, the Department of Commerce, the Land-Grant institutions and others have all been examining this issue. It is evident from the results of these efforts that much more work needs to be done both in researching the problem and in maintaining an adequate environmental monitoring program.

Our estimates of economic loss due to the effect of air pollution on crop yields are inexact measurements. They range from estimates of a few billion dollars a year up to many billions of dollars. We still do not understand the effects of current levels of photooxidants such as ozone -- sulfur dioxide, and acid rain on our crops and forests. We cannot adequately monitor chronic crop losses--crop losses of under ten percent--that occur without evidence of vegitative damage. We cannot adequately predict what future losses may be with planned changes in energy sources and industrial development.

The District that I represent in Southern California has seen the effects of air pollution on agriculture and forestry. I am not proud of the fact that the Los Angeles Basin has become an internationally known laboratory for studying the effects of air pollution on vegetation. I do not want to see other areas of this country so honored.

This hearing is timely. The Subcommittee on Department Operations, Research, and Foreign Agriculture is holding a series of hearings on research on our agricultural resource base--water, soil, and air--of which this joint hearing is one part. And, we in Congress will be making a number of decisions in coming months on the Clean Air Act for which information obtained today will be helpful.

I look forward to hearing the testimony which will be presented this morning.

Mr. BROWN. In the event my distinguished colleague has an opening statement, it will be inserted in the record at this point.

[The opening statement of Mr. Scheuer follows:]

HON. JAMES H. SCHEUER

JULY 9, 1981

THANK YOU MR. CHAIRMAN.

TODAY'S HEARING PROVIDES THE SUBCOMMITTEES WITH AN OPPORTUNITY TO UPDATE AND EXPAND HEARINGS HELD IN 1979 WHICH WERE ON "AGRICULTURAL PRODUCTIVITY AND ENVIRONMENTAL QUALITY."

THESE EARLIER HEARINGS WERE HELD WITH THE NATURAL RESOURCES SUBCOMMITTEE AND THE AGRICULTURE SUBCOMMITTEE ON CONSERVATION AND CREDIT.

DURING THESE 1979 HEARINGS SEVERAL SIGNIFICANT ISSUES WERE RAISED.

SUCH AS: THE COMBINED EFFECT OF POLLUTANTS IS SERIOUS, OZONE CAN CAUSE WIDESPREAD DAMAGE, AND ACID RAIN CAN CAUSE BOTH BENEFICIAL AND DETRIMENTAL EFFECTS.

HOWEVER, THERE WERE SEVERAL QUESTIONS THAT WERE LEFT UNANSWERED, SUCH AS:

1. WHAT IS THE NATIONWIDE IMPACT OF AIR POLLUTION ON AGRICULTURE BOTH IN TERMS OF YIELD AND ECONOMIC LOSSES?

2. WHAT IS THE EFFECT OF THE INTERACTION OF TWO OR MORE POLLUTANTS ON AGRICULTURE?

3. WHAT IS THE CORRELATION BETWEEN THE RESULTS OF EXPERIMENTS CONDUCTED IN THE GREENHOUSE AND THOSE CONDUCTED IN THE FIELD?

4. DO THE RESEARCH RESULTS ACCURATELY PORTRAY WHAT IS OCCURRING IN THE FIELD?

WE HOPE THIS HEARING WILL HELP PROVIDE ANSWERS TO THESE AND OTHER QUESTIONS, WHICH SHOULD GIVE US SOME GUIDANCE IN SETTING RESEARCH PRIORITIES FOR THE VARIOUS AGENCIES.

IN ADDITION, THE ANSWERS PROVIDED HERE TODAY WILL ENABLE US TO SEE THE OVERALL PICTURE OF THE IMPACT OF AIR POLLUTION ON AGRICULTURE.

THIS IS ESPECIALLY IMPORTANT NOW THAT CONGRESS IS BEGINNING THE LEGISLATIVE PROCESS FOR THE REAUTHORIZATION OF THE CLEAN AIR ACT.

PRESENTLY THE ACT PROVIDES FOR SECONDARY AMBIENT AIR QUALITY STANDARDS WHICH ARE DESIGNED TO PROTECT AGRICULTURE.

HOWEVER, THESE STANDARDS WERE ELIMINATED IN AN EARLY DRAFT OF THE ADMINISTRATION'S RECOMMENDATIONS REGARDING THE ACT.

I THINK THIS IS A MISTAKE FOR SEVERAL REASONS.

SEVERAL RESEARCH STUDIES HAVE INDICATED THAT VEGETATION IS MORE SENSITIVE TO CONCENTRATIONS OF OZONE AND OF SULFUR DIOXIDE THAT have been ~~ARE LOWER THAN HAS BEEN~~ DETERMINED TO BE INJURIOUS TO HUMAN HEALTH.

IN ADDITION, THE ELIMINATION OF THE SECONDARY STANDARDS APPARENTLY REPRESENT THE ADMINISTRATION'S VIEW THAT AIR POLLUTION DOES NOT SEVERELY IMPACT ON AGRICULTURE.

OUR HEARINGS IN 1979 INDICATED OTHERWISE AND THE HEARING TODAY, BASED ON PRELIMINARY TESTIMONY, WILL ALSO INDICATE THE NECESSITY OF PROTECTING AMERICA'S AGRICULTURE FROM AIR POLLUTION.

THANK YOU MR. CHAIRMAN.

Mr. **BROWN**. We welcome our first witness this morning, who is Dr. Howard Heggestad of the Plant Physiology Institute, U.S. Department of Agriculture, who will give us an overview of research effects of oxidants.

Mr. **CARNEY**. Mr. Chairman, at this time, too, I would like to insert an opening statement.

Mr. **BROWN**. I beg your pardon. I certainly wish to recognize you for your opening statement.

Mr. **CARNEY**. I think, due to the hour, I will submit it for the record.

Mr. **BROWN**. Without objection, all the opening statements will be inserted.

Mr. **CARNEY**. Thank you, Mr. Chairman.

[The opening statement of Mr. Carney follows:]

OPENING STATEMENT BY
HON. WILLIAM CARNEY, RANKING MINORITY MEMBER
SUBCOMMITTEE ON NATURAL RESOURCES, AGRICULTURE RESEARCH AND ENVIRONMENT

Hearing on Impact of Air Pollutants on Agriculture Productivity

July 9, 1981

Mr. Chairman, we are addressing today a problem that is somewhat difficult to get a handle on, and I hope our distinguished witnesses will do their best to make the nature of the problem and the possible solutions clear to us.

From my examination of the subject so far, it seems that the main danger to agricultural productivity from air pollution is an economic one, with crop losses from various pollutants running perhaps in the range of $5-10 billion per year. That in itself is enough to frighten me, coming as I do from a district with a large agricultural base. However, when I also consider the indirect effects of air pollution that are not as easily expressed in monetary terms -- increased susceptibility of crops to diseases, delayed maturation of crops, increased difficulties in production and marketing -- then I realize that we have a serious problem that must not be allowed to get out of hand.

UNFORTUNATELY, WHILE THE IMPACTS OF AIR POLLUTION ON AGRICULTURE MAY BE MEASURABLE IN A FINAL SENSE, SUCH AS ECONOMIC DAMAGE, THERE ARE OTHER FACTORS THAT MAKE THE SUBJECT MORE DIFFICULT TO GRASP. MANY CROPS, FOR EXAMPLE, SUFFER AIR POLLUTION DAMAGE WITHOUT ANY VISIBLE SYMPTOMS. HOW THEN DO WE KNOW THAT THE DAMAGE IS OCCURRING? ALSO, LEVELS OF AIR POLLUTION THAT DO NOT PRESENT A DANGER TO HUMAN HEALTH CAN STILL BE DAMAGING TO CROPS. SHOULD OUR CONCERN THEREFORE BE ANY LESSER THAN IF HUMAN HEALTH WERE AT STAKE?

QUESTIONS SUCH AS THESE CAN BE ANSWERED ONLY THROUGH THE AVAILABILITY OF SOUND SCIENTIFIC DATA ON WHICH DECISIONS CAN BE BASED. SUCH DATA CAN OFTEN BE OBTAINED ONLY THROUGH RESEARCH AND DEVELOPMENT PROGRAMS, AND THAT BRINGS US TO THE QUESTION OF WHETHER CURRENT PROGRAMS ARE ADEQUATE, OR WHETHER NEW ONES ARE NEEDED. IN THIS ERA OF FISCAL RESTRAINT, THE ESTABLISHMENT OF NEW GOVERNMENT-FUNDED PROGRAMS IS NEITHER DESIRABLE NOR LIKELY, BUT THE BENEFITS OF ADDITIONAL INFORMATION MUST BE BALANCED AGAINST POSSIBLE SAVINGS IN CROP DAMAGE. THAT IS WHAT I HOPE THE WITNESSES CAN BRING OUT, AND HELP US DECIDE.

FINALLY, WE MUST ALSO KEEP IN MIND THE COMPETING DEMANDS OF SOCIETY CONCERNING THE QUALITY OF OUR AIR. FOR EXAMPLE, CURRENT ENERGY PLANS CALL FOR AN INCREASED USE OF COAL TO

GENERATE ELECTRICITY, AND THAT MEANS GREATER PRODUCTION AND RELEASE OF SULFUR DIOXIDE INTO THE ATMOSPHERE. UNFORTUNATELY, PLANTS ARE MORE SUSCEPTIBLE TO SULFUR DIOXIDE THAN ARE PEOPLE, AND THE POTENTIAL FOR ADDITIONAL CROP DAMAGE IS DIRECTLY RELATED TO THE EXTENT TO WHICH OUR ENERGY PLANS ARE REALIZED. MY FIRST QUESTION TO THE FIRST WITNESS, THEN, WILL BE HOW DO WE SET THESE PRIORITIES, AND BALANCE THE POSSIBLY CONFLICTING NEEDS FOR FOOD AND ENERGY? I'M GLAD THAT I CAN ASK THIS QUESTION, RATHER THAN BE THE ONE WHO HAS TO ANSWER IT.

MR. CHAIRMAN, THAT COMPLETES MY OPENING REMARKS, AND I THANK YOU FOR THE OPPORTUNITY TO MAKE THIS STATEMENT. I AM LOOKING FORWARD TO THE TESTIMONY OF OUR WITNESSES.

Mr. Brown. Thank you very much for being here, Dr. Heggestad.

STATEMENT OF HOWARD E. HEGGESTAD, RESEARCH PLANT PATHOLOGIST, PLANT STRESS LABORATORY, AGRICULTURAL RESEARCH SERVICE, U.S. DEPARTMENT OF AGRICULTURE

Dr. Heggestad. Thank you, Chairman Brown. It is a privilege to be here.

I am Howard E. Heggestad, research plant pathologist with the Department of Agriculture, Beltsville, Md. I do appreciate the opportunity to appear before you today regarding research on the impact of air pollutants on crop productivity.

Most of my research at Beltsville has concerned the effects of photochemical oxidants, primarily ozone, on crops. We have also been rather interested in and made some, I think, rather significant contributions to show that mixtures of ozone and sulfur dioxide can reduce the threshold by which we find leaf injury and, more recently, have shown that pollutant mixtures can reduce the threshold at which pollutants cause yield effects.

Plant species are very sensitive to air pollutants, but within each species there is a range of cultivar sensitivity. We in agriculture have tried to minimize crop losses by pointing out which cultivars are tolerant and which are the more sensitive. Thereby growers may avoid the sensitive ones and use the more tolerant ones. A good grower, placing emphasis on yield, who gets his cultivars from the area in which he is growing his crop—and where there is much breeding work in the area such as with corn in the central part of the country—will find those cultivars to have as much tolerance to photochemical oxidants as any that might be available.

Now, attached to my statement I have a photograph of some open-top chambers. This represents a forward step in technology. We are able to introduce pollutants of known concentration and expose the plants to various doses of these pollutants, either singly or in combination. This technology requires lots of tubing to send the pollutants out to the plots and tubing to bring them back so we can monitor them.

There has been a rather significant recent development that I think is worthy of note, and that is the National Crop Loss Assessment Network initiated last year by the Environmental Protection Agency. The network proposes to do a better job in assessing impacts, especially of ozone and SO_2, and to some extent NO_2, on the growth of crops. Major crops, such as soybeans and corn, will be looked at rather than known sensitive crops such as snap beans and potatoes. We will look at major crops in different regions of the country.

That is very important because, as we all know, a species, whether it be tree or annual crop, when grown in an arid area, it has more tolerance to air pollutants than when grown in humid areas. There have been some new techniques other than open-top chambers for assessing the effects of air pollutants, and that includes introducing sulfur dioxide over a soybean field through perforated pipes but no chambers. A problem with this technique is that replications are difficult and almost impossible. Also, in dealing with these rather large plots you can only expose when the wind is blowing in the direction away from the control plots.

With respect to oxidants, we have a rather unique tool from the Du Pont Chemical Co. They have an experimental compound called EDU that when applied as a spray or drench to sensitive plants will within 24 hours change them to plants very resistant to ozone. The application of that chemical, or some other chemicals having somewhat similar effects, provides a means of determining the amount of yield loss caused by oxidants. EDU, where it works, gives almost full protection. Yields of plants which are not protected compared to those protected will give investigators some idea of the impact of ozone. It does not work against PAN or SO_2 and any of the other pollutants tested. It does not work as well or as quickly on some species as others.

Now, we have worked since 1972 with open-top chambers obtained originally from the Environmental Protection Agency. In table 1 there is a summary of our results. We have used these chambers on potatoes, soybeans, sween corn, snap beans, and tomatoes. There were replications of the different treatments in different parts of the field, and in different years.

Now, if you compare the yield in the nonfiltered chambers with the yield in carbon-filtered air, with most of the pollution removed, there was about a 90-percent yield in nonfiltered air with potatoes, only 80 percent with soybeans, 91 percent with sweet corn, 96 percent with snap beans, and 83 percent with tomatoes.

We look at the figure in the righthand column and find that in the case of potatoes and soybeans the yield without a chamber was about as good as that in the carbon-filtered air. This means that there is some chamber effect even with open-top chambers. We do not have evidence, though, when we compare filtered and nonfiltered chambers, that growing plants in the chambers either increases or decreases sensitivity to air pollution.

Now, I wish to call to your attention some of the results that have not been published—table 2 and figure 2. In table 2 we show the yield loss after adding SO_2 to snapbeans in one case to charcoal filtered air and in another case, with more treatments, to nonfiltered air. Please note that adding this relatively high dose of SO_2 in charcoal-filtered air reduced yield only 15 percent, but adding the same SO_2 dose to nonfiltered air reduced yield about 45 percent even though oxidants alone had no measurable effect on snap beans yield in that year.

The graph—figure 2—shows when we average the yield for three varieties we find a very linear relation between SO_2 treatments in the nonfiltered air and bean yields. This means that anyplace along that line there is a significant yield effect. We can also expect that at levels less than 0.06 ppm SO_2 or 60 parts per billion there would be some effect.

Now, at some lower value, SO_2 would have beneficial effects. Our experiments at this time have not identified where that might be. It may be at 0.02 ppm in this kind of experiment. SO_2 effects on crop yield are not linear over a wider dose range. There is some benefit of SO_2.

Looking at tables 3 and 4, we find some data on tomatoes. Table 3 shows the effect of SO_2 and ozone on ripe fruit. We find adding the quarter part per million of SO_2 in carbon-filtered air reduces the yield about 22 percent, whereas in nonfiltered air, where there are more oxidants, the yields are reduced about 32 percent. Oxidants alone caused a reduction of 17 percent. The effects of adding the SO_2 was somewhat the same as the oxidant effect. Tomatoes, or at least the cultivar Jet Star, is rather sensitive to oxidants.

If you look at the total fruit yield in table 4, we find that the impact of SO_2 doesn't seem to be as great, only a 10-percent loss in carbon-filtered air, and about 18 percent in nonfiltered air. Oxidants reduced the yield about 5 percent, the yield being 95 percent of that in carbon-filtered air.

Now, the reason for the difference between tables 3 and 4, the data coming from the same experiment, is table 4 deals with green fruit harvested at the close of the experiment, and table 3 deals only with the ripe fruit. The ripe fruits are surrounded by older leaves that are senescent and dying due to the pollutants, whereas the green fruits are surrounded by leaves that have still a lot of protection against ozone and SO_2 and they are not affected. This is certainly one possible explanation.

I would call your attention to table 5, which is the experiment run last year. We have added two concentrations of SO_2 to the carbon-filtered air, and we have five in nonfiltered air. If we look at figure 3, we find that in the range from zero to about a quarter part per million SO_2 there is a very linear relation between the concentration of SO_2 and the yield of ripe tomato fruits. Adding more of the SO_2 did not cause more loss. The leaves apparently were damaged as much as possible by 0.24 ppm SO_2.

Now, in carbon-filtered air you will note there was a linear response, $r = -.99$, which means anything along the line is likely to be significant, and from zero to 24 in the nonfiltered air is also quite linear, $r = -.98$.

Now, Mr. Chairman, I brought with me some data from Ron Oshima which is from a published study by the California Air Resources Board. The yield data are arranged differently than by

Oshima, but I think as now arranged it reflects pretty much the same response as shown by our data. [Document distributed.]

In the case of the Oshima-California study, there were sufficient oxidants to get information on dose-response by dilution; that is, 100-percent filtered air, 75 percent, 50 percent, 25 percent, and zero. These are yields of red kidney beans, and you will note by the top dotted line with 100 percent, 75 percent, 50-percent filtered air, without SO_2 added, there was really no effect on yield.

But, adding 100 parts per billion or a tenth of a part per million SO_2 to these treatments, you begin to get a yield loss. There was a very significant effect when you mix a tenth of a part per million SO_2 with 50 percent filtered, 50-percent nonfiltered air. At that level oxidants alone are just below the threshold of causing a yield effect, adding the SO_2 really brings the yield down. In other words, there was a significant interaction.

When you have 25 or 0 percent charcoal filtered air, adding the SO_2 caused no more yield effect. That is much like our results on tomatoes when we added more than 0.25 ppm SO_2.

This data does not give us a handle on total losses in agriculture caused by the air pollutants SO_2 and ozone, but it certainly does point out that one must take into account the effects of gas mixtures, especially that of ozone and SO_2 in assessing yield loss. Some people may wonder, "why don't we have more information on actual yield loss at the present time?" Well, the studies discussed are rather new; that is, in the last 10 years. We started in 1972 with the open-top chambers. Before that time the big emphasis was on leaf injury, whether it be injury to tobacco or to some other crop. There were some studies, for example, in Germany where they measured yields of potted plants downwind from a smelter emitting SO_2.

Now we know there may not be, depending upon when the injury occurs, a real relation between leaf injury and the yield loss. I really believe, with the multidiciplinary activity in the national crop loss assessment network there is a chance of getting a much better data base than we have at the present time. I think generally poor crop loss data accounts for the big differences we have in the estimates of economic loss. SRI—Sanford Research Institute—had about a $325 million loss in 1971, and a decade later they come up with $1.7 billion in losses. There is something wrong with that so far as I am concerned.

I don't believe that I could add much to explaining why, but at least a part of it is due to the data base which is inadequate. In some cases economists have used a data base which reflects losses by sensitive plants under growing conditions which may have increased sensitivity. They have tried to extrapolate from this to the entire country.

In one case—not necessarily the one I mentioned—I know where some economists used sweet corn data and extrapolated to field corn. That won't work. It won't wash. You can't use potato data either from the Eastern part of the country and apply it to potatoes in Idaho where the crop is irrigated. These kinds of studies will really have to be looked at critically.

I believe, Mr. Chairman, this is a pretty good synopsis of what I have in this document.

[The prepared statement of Dr. Heggestad follows:]

STATEMENT OF DR. HOWARD E. HEGGESTAD
RESEARCH PLANT PATHOLOGIST
PLANT STRESS LABORATORY
AGRICULTURAL RESEARCH SERVICE
U.S. DEPARTMENT OF AGRICULTURE

Mr. Chairman and Members of the Committee, I am Dr. Howard E. Heggestad, Research Pathologist, at the U.S. Department of Agriculture's Beltsville Agricultural Research Center. I appreciate the opportunity to appear before you today regarding Research of the Impact of Air Pollutants on Crop Productivity.

Most plant species are sensitive to air pollutants, but only the most sensitive cultivars within these species may be reduced measurably in productivity at present levels of the two major pollutants, ozone and sulfur dioxide. For more than a century, it has been known that agricultural crops downwind of certain industries were damaged by sulfur dioxide and flourides. More recently, we have learned that photochemical oxidants (primarily ozone) are damaging to sensitive crop species in certain regions of the country. For various reasons injury to foliage is not as common at the present time as two decades ago. But we have learned that crop losses can occur without visible injury or only some premature aging and loss of leaves. Also, crops which produce fruit, as various beans and cotton, may have considerable foliar injury without loss in productivity. The measurement of crop losses due to air pollutants is complex due to the variability in pollutant levels each day and each season, and due to interactions between the pollutant(s) and genetically diverse species (many cultivars). Also, environmental conditions alter plant sensitivity to pollutants. Plants grown in the arid regions of the country are not as sensitive to ozone and sulfur dioxide as plants grown under humid conditions.

The techniques used to assess impact may alter the result, for example the results obtained with older closed chambers are likely to be different from results obtained with open-top chambers (Figure 1). Greenhouse effects were a concern with closed chambers. With open-top chambers, these problems have been minimized, but there can be considerable nonfiltered ambient air entering the open top and mixing with charcoal-filtered air within the chamber. The chambers help separate the effects of air pollution from effects of other stress factors on productivity such as inadequate soil moisture, too high or too low air temperatures, poor nutrition, soil compaction, etc.

We recognize limitations in our efforts to quantitatively assess the impact of air pollutants on crop productivity especially when differences in yield are less than 10% due to treatments. Increasing the replications of each treatment and repeating the experiment for at least three seasons improves our ability to detect significant differences between treatments. Current research gives emphasis to pollutant dose-response studies and the use of regression analyses to identify significant trends.

A very important new development for assessing air pollution impact is the National Crop Loss Assessment Network (NCLAN) initiated in 1980 by the Environmental Protection Agency. A multidisciplinary, multiagency research management committee plans research which is carried out in five different regions of the country. Restrictions are imposed in an effort to provide, as soon as possible, the most useful information; that is, the research program is currently limited to three pollutants and their mixtures and to tests with important cultivars and crop species at five locations in the country. To the extent feasible the treatments and experimental conditions are the same at two or more locations. The NCLAN approach also involves quality assurance procedures so far as measuring pollutants, monitoring environmental parameters, and in taking biological data to assess crop yield, plant growth and crop quality.

Prior to the development of NCLAN the field studies tended to be more varied using crops known to be relatively sensitive to air pollution (i.e. problem crops). There was greater dependence on data obtained in controlled environment chambers which rarely duplicated field situations. Frequently, yield losses were based on ratings of foliar injury since few crops could be grown to maturity under laboratory or greenhouse conditions. In the last decade, a greater orientation to field studies at some research locations has resulted in the development of improved techniques as each investigator utilized previous experiences, available resources and local conditions to obtain more adequate information on the impact of air pollutants on crop productivity.

Our research objectives include also the development of technology to minimize crop losses as by identification of tolerant cultivars and by application of protective chemicals.

Techniques for assessing impact of gaseous pollutants include: a) a comparison of crop yields at locations with pollution gradients such as downwind from a significant point source or in the L.A. basin from the seashore to the mountains; b) assessing crop productivity with closed or various kinds of open-top chambers equipped with nonfiltered ambient air or charcoal filtered air; c) using perforated pipes supported above the crop to expose crops to one or various doses of SO_2; d) the addition of various doses of pollutants in chambers and e) the use of chemicals to protect plants from ozone injury. The increased yield of protected over unprotected plants is a good measure of ozone impact.

The research with oxidants has increased, but it falls short of providing the information really needed to assess economic impact due to ambient levels of oxidants or to predict impact if oxidants decrease or increase.

Our research on ozone as an air pollutant has been varied since 1959 when we, jointly with the University of California Riverside, were first to report that a photochemical oxidant (ozone) was the cause of weather fleck on tobacco in Eastern United States. This established that photochemical smog damaged crops in Eastern U.S. as well as in California. In 1966, we discovered that sulfur dioxide and ozone in gas mixtures acted synergistically to injure tobacco leaves at concentrations which were too low to cause injury as single pollutants. We identified Bel-W3 tobacco as a very sensitive biological indicator of ozone. The cultivar has been used in many countries to indicate elevated levels of ozone. We determined the relative sensitivity to ozone of cultivars of several crop species (e.g., snap bean, soybean, lima beans, tobacco, potatoes, sweet corn), used chemicals to prevent ozone injury, and developed information on the mechanism of action of ozone and the antiozonant EDU developed by E. I. Dupont DeNemours and Company. Several colleagues at Beltsville participated in the research.

In 1972, we began a research program with open-top chambers to assess the impact of ambient oxidants on crops. Plants of several species were grown from the seedling stage to maturity in these field chambers supplied with either charcoal-filtered or nonfiltered ambient air. Our results with the open-top chambers are summarized for 5 species in Table 1. The data indicate a 12 percent reduction in yield due to elevated oxidants. Greatest impact was on soybeans (20% loss) and least on snap beans (4% loss). Since potatoes and soybeans produced as much in plots without chambers as in carbon filtered air and tomatoes less in plots without chambers, there may be some chamber effects. There is no evidence, however, that the chambers increase or decrease plant sensitivity to ozone. The charcoal-filtered air, which is used as a standard of comparison in determining yield losses has a normal background level of ozone even though filtered. Ozone in the chambers may be 20 to 50% of that of the polluted ambient air due to entry of nonfiltered air into the chamber through the open top especially when wind speeds are elevated. Chamber efficiency in reducing ozone levels is greatest during periods of low wind speed, which is characteristic of episodes of high air pollution.

Estimates of yield losses using open-top chambers on snap beans were similar to results obtained with snap beans in Massachusetts when plants were protected from ozone injury with antiozonant chemicals rather than with chambers. A study with dry, white beans in Ontario, Canada, revealed the application of the antiozonant, EDU, increased yields 36%. These somewhat similar results with other methodology seems to indicate that the use of open-top chambers can provide meaningful assessments of ozone impact on crop yields. In one of the two seasons with sweet corn, our data shows only Silver Queen with a statistically significant yield loss, yet it was the highest yielding of four cultivars tested. With all sweet corn cultivars, the ears from plants in carbon-filtered air were filled at the tips significantly more than from plants in nonfiltered chamber plots or in plots without chambers. Our five years of research with snap beans involving two crops each summer indicated the greatest impact of ozone on bean yields was not in the years with highest average ozone concentration. A single episode at blooming or early pod filling time had greater impact on yield than a somewhat elevated average ozone concentration throughout the season. Maturity alters plant sensitivity to ozone and there can be significant interactions with environmental parameters. Highest average ozone occurs on sunny days when temperatures are high and rainfall is low. These are factors which also tend to make most plants more tolerant to elevated ozone.

Ozone increases crop losses attributable to sulfur dioxide. Beginning in 1979, we began investigating the effect of additions of low concentrations of SO_2 on crop productivity when plants were grown with two levels of ozone, charcoal-filtered ambient air vs. nonfiltered ambient air.

Data in Table 2 and Figure 2 provide a brief summary of our results. The impact of SO_2 was about threefold greater in nonfiltered air containing ambient ozone than in charcoal-filtered air where the ozone concentration was reduced about 70%. This happened even though, in 1979, ambient oxidants without SO_2 (NF) had no measurable effect on snap bean yields. The fact that such a high linear correlation (r = .99) was found (Fig. 2) between dose of SO_2 and yield reduction of beans suggests that SO_2 doses lower than our lowest (0.06 ppm for 6 hr/day and 5 days/week) could have a detrimental effect on bean yields in the presence of existing levels of ambient oxidants. In the 1979 season, soil moisture was very favorable for plant growth. We believe the plants were generally more sensitive to ozone than in seasons with less rainfall.

We have results of two seasons of research with tomatoes grown also in open-top chambers with additions of low doses of SO_2 in charcoal-filtered, and nonfiltered air. A view of the chambers and long lines of tubing needed for the addition of the SO_2 gas and for monitoring SO_2 and O_3 levels in the chambers is shown in Figure 1. In 1979, our experiment involved 7 treatments and three replications of each treatment. In 1980, there were 9 treatments with 3 replications of each treatment.

The 1979 data are summarized in Tables 3 and 4. By a comparison of data in these two tables, we note SO_2 had greater impact on the ripe tomato fruit yields (Table 3) than on total fruit yields (Table 4). The latter included many young green fruits removed at final harvest. Ozone does not visibly damage younger leaves which support the growth of young fruits. It is the older fully expanded leaves which are damaged most by ozone. Chlorophyll needed for photosynthesis is reduced first and leaves die prematurely. Consequently, there are inadequate food reserves to support the maturing fruit, so fruit size and total ripe fruit yields are lowered.

The impact of additions of SO_2 in nonfiltered air was greater than in charcoal filtered air; e.g. 0.25 ppm/SO_2/6 hr./day reduced total fruit yield 9.2% in CF air and 17.4% in NF air (Table 4). Of the 17.4% yield loss, at least 4.8% was due to oxidants and about 12.6% to SO_2. Sulfur dioxide (0.25 ppm) reduced ripe fruit yields 22.3% in CF air compared to 31.5% yield reduction due to SO_2 and oxidants in combination (Table 3). Oxidants alone reduced ripe fruit yields 17.1%.

In 1980, we had 3 treatments of SO_2 in charcoal-filtered air (0, 0.12 and 0.48 ppm) and 5 treatments in non-filtered air (0, 0.06, 0.12, 0.24 and 0.48 ppm). Exposures were for 5 hr/day, 5 days/week over a 10 week period. These concentrations of SO_2 are found in areas with significant SO_2 pollution; however, the duration and frequency for the two highest concentrations are much greater than expected at most sites. Data in table 5 and in figure 3 summarize the results. As in the 1979 season, the effects of SO_2 and oxidants on tomatoes were additive. Oxidants alone reduced the yield of Jet Star tomato 16.6% , compared to 17.8% for the highest dose of SO_2 . Mixtures of ambient oxidants and 0.24 ppm SO_2 reduced the yield 33%. Doubling the SO_2 dose to 0.48 ppm did not increase the yield loss in

NF air. Data shown in Figure 3 reveal significant linear correlations between increasing SO_2 exposure concentrations added to charcoal-filtered air (r = .99) and to nonfiltered air (r = .90). The correlation was higher (r = .98) in nonfiltered air over the SO_2 range from 0-0.24 ppm since 0.48 ppm did not increase yield loss.

The trends revealed by regression analyses in Figures 2 and 3 suggest for snap beans and tomatoes that doses of SO_2 lower than those used in our studies could have detrimental effect on the yields of these species if there are elevated levels of oxidants. Fortunately, at present, the levels of SO_2 are quite low in most of the agricultural areas of the country. Concentrations rarely exceed 0.10 ppm.

In 1981, we will conduct similar research with soybeans. There will be a lower dose of SO_2 (.03 ppm). It is well known that some atmospheric sulfur benefits plant growth. Also, in 1981, we will be adding two levels of ozone to 12 chambers having a range of SO_2 treatments. This should provide data useful in predicting the effects of SO_2 if ambient ozone increases. Our research in 1981, as in 1980, is a part of the National Crop Loss Assessment Network which involves cooperation of three federal agencies, a state agency and a private insitution: i.e., E.P.A, Corvallis Oregon; USDA, Beltsville and Raleigh; DOE and EPA, Argonne, Ill.; Univ. California, Riverside; and Boyce Thompson Institute for Plant Research, Ithaca, NY.

1. The National Crop Loss Assessment Network (NCLAN) needs continued research to obtain a reasonable data base.

2. Dose-response experiments should be conducted using fluctuating concentrations which simulate ambient frequency distributions rather than 'square wave' type exposures given in most exposure regimes. This is somewhat difficult to accomplish, but computer controlled devices have potential for simulating normal frequency distributions.

3. There should be research to develop improved methodology for assessing impact of air pollutants in field situations.

4. The levels of SO_2 and O_3 should be monitored in more rural areas and the data summarized with at least 3-hr. averages for SO_2 and 7 or 8 hr highest daytime O_3 averages. This information is needed to guide the dose-response studies used in assessing impact of these pollutants on crop productivity and to interpret results from dose-response studies already conducted.

5. It is essential that we determine threshold concentrations (doses) for pollutants singly and in combinations for effects on yield, photosynthesis, respiration and transpiration. Information is especially needed using long term, entire season, exposures. Such studies with very low concentrations of pollutants could yield information also on potential benefits of uptake of atmospheric sulfur and nitrogen.

6. Most of the research to identify the relative sensitivity of cultivars within species to air pollutants has been done using concentrations which produce acute foliar injury. Research is needed to assess the relative sensitivity of crop cultivars as measured by yields and quality of the useable product produced, to long term exposures with low levels of pollutants. It should be recognized that plant breeding research which is done in areas with elevated levels of pollutants, will result in cultivars more tolerant to pollutants than if the breeding is done only in areas with clean air or very low levels of air pollutants.

7. There is a concern in the National Atmospheric Deposition Program (NADP) for the long-term effects of acid precipitation and acid gas deposition on plant and soil productivity (both positive and negative effects). USDA and the State Experiment Stations sponsor the NADP.

8. Research is needed on the mechanisms of action of pollutants to aid in evaluating and predicting results.

9. Continued research on physiological crop models may provide useful tools in relating laboratory and green house studies to field situations and in predicting crop response to pollutants when grown in regions of the country with very different environmental conditions.

10. To acquire adequate information on impact of air pollutants on crop productivity multidisciplinary team research should be supported involving crop production specialists, air pollution scientists, engineers, economists and statisticians. The NCLAN program has made a good beginning in the direction needed.

In 1971, the Stanford Research Institute (SRI) estimated photochemical oxidants caused $121 million of a $135.5 million total loss on plants in the U.S. caused by oxidants, sulfur dioxide and fluorides. One decade later, 1981, SRI estimated crop losses from air pollutants to be $1.8 billion with $1.7 billion caused by ozone and other oxidants. The latter figure reflects the availability in the past decade of crop yield loss data using open-top chambers and other techniques. Previous estimates relied primarily on the assessment of relative amounts of leaf injury. The new SRI estimates and other new estimates may be high because the early efforts to assess crop yield losses tended to involve air pollution sensitive crops and cultivars which had shown evidence of leaf injury due to air pollutants; i.e., a problem of some sort had been identified. Broad generalizations have been made using an inadequate data base, with respect to yield reductions caused by ozone and sulfur dioxide on important cultivars of major crop species as grown in different regions of the country. This will not improve until present research efforts in field situations involving major pollutants singly and in combinations have been in place long enough to examine seasonal effects and the variation in response expected in different regions of the country when using similar technology to evaluate impact.

It seems from existing data on pollutant mixtures that there are possibilities of significant yield losses without any visible damage to leaves, except some premature chlorosis and leaf loss. An awareness by growers of the possible impact of air pollutants in achieving maximum productivity will further motivate them to select cultivars which consistently produce good yields and quality. Such cultivars are likely to be those with satisfactory tolerance to pollutants. Air pollution problems with perennials including tree species could be greater than those with annual crops where a cultivar change is relatively easy to make compared to perennials. It is also more difficult to assess the impact of air pollutants on productivity of most perennials, especially tree species.

In the future, new air pollution problems will develop on vegetation as technology changes. The need will continue for highly trained biologists to conduct research on the effects of phytotoxic air pollutants. The ability to judge normal crop growth and to distinguish between damage from air pollutants and that caused by other environmental stresses are prerequisites for effective assessments of air pollution impact.

Mr. Chairman, this completes my prepared statement. I shall be pleased to respond to any questions you may have.

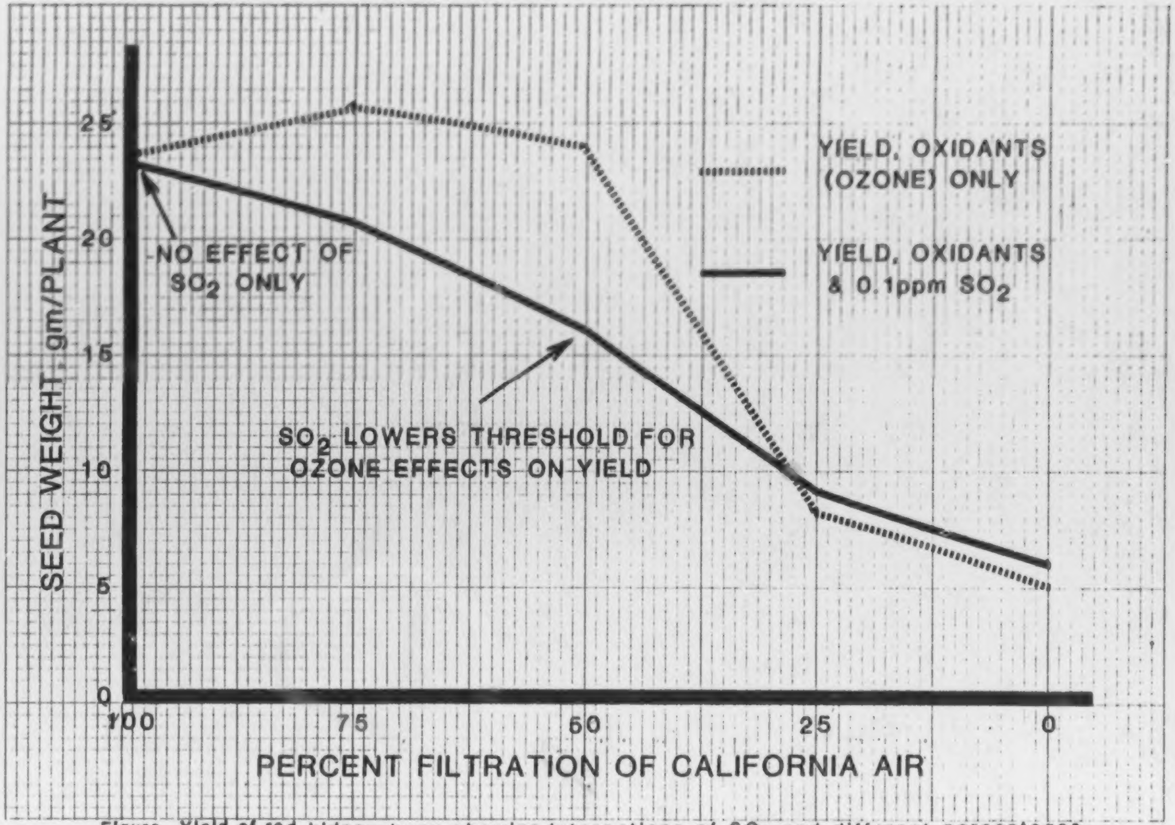


Figure Yield of red kidney bean showing interactions of SO_2 and different percentages ambient oxidanta in California. From Ron Oshima U. of CA. Riverside

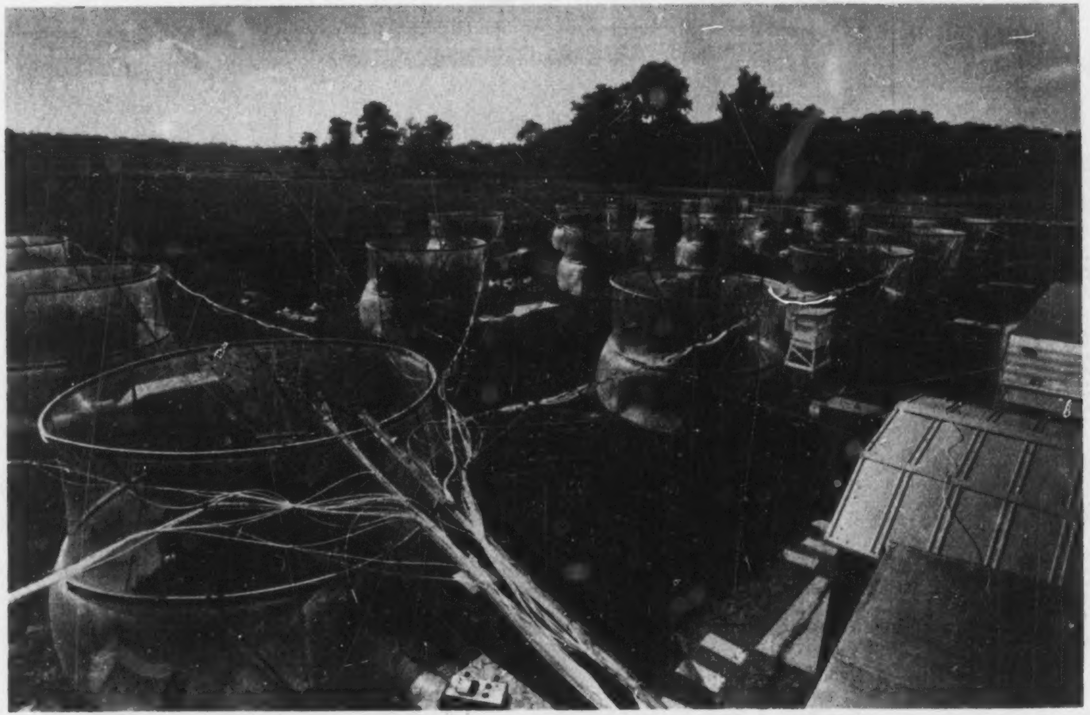
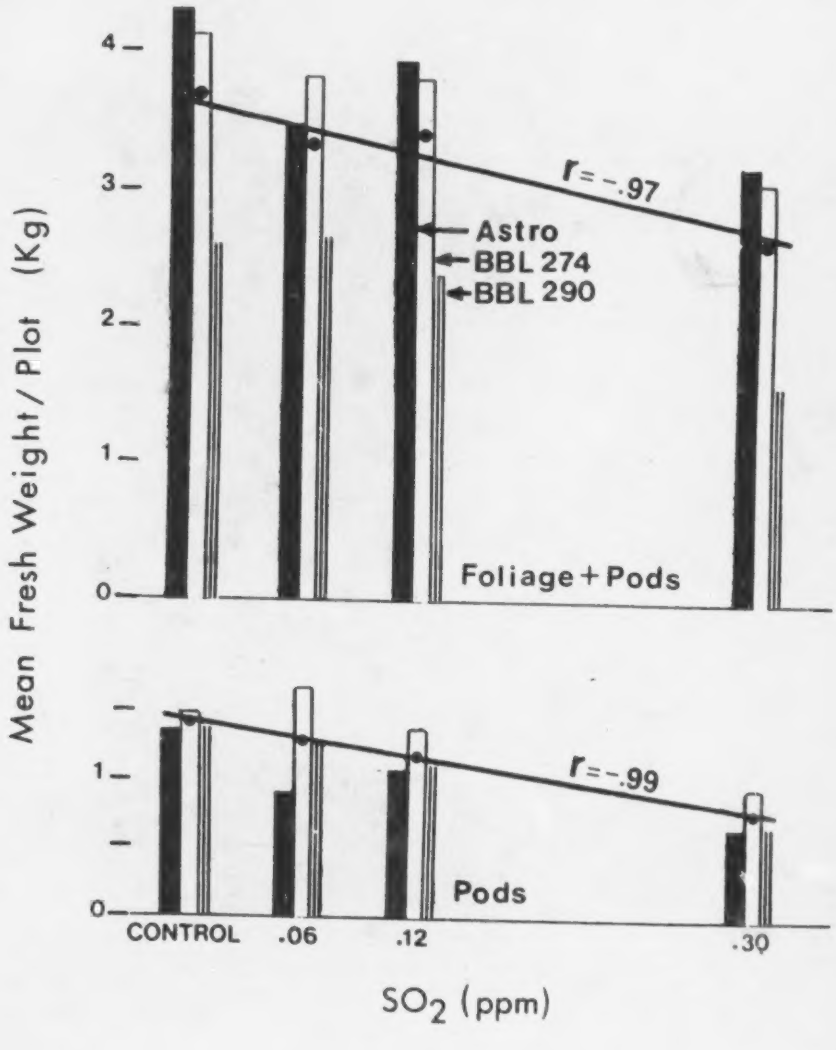


Figure 1. Sixteen of twenty-four open-top chambers used for the tomato experiment in 1980. Blowers force air through the double wall lower panels which serve as the air duct. Air enters chamber interior through holes in the inner wall. After circulating through the plant canopy the air exits the chamber top. Chamber air is replaced about four times each minute. The tubing is used to bring pollutants to blowers where they are mixed with the air prior to entering the chambers. Instruments and other equipment needed to disperse and monitor pollutants are in the trailer on right.

Effect of the addition of SO2 in varying concentrations on snapbeans.



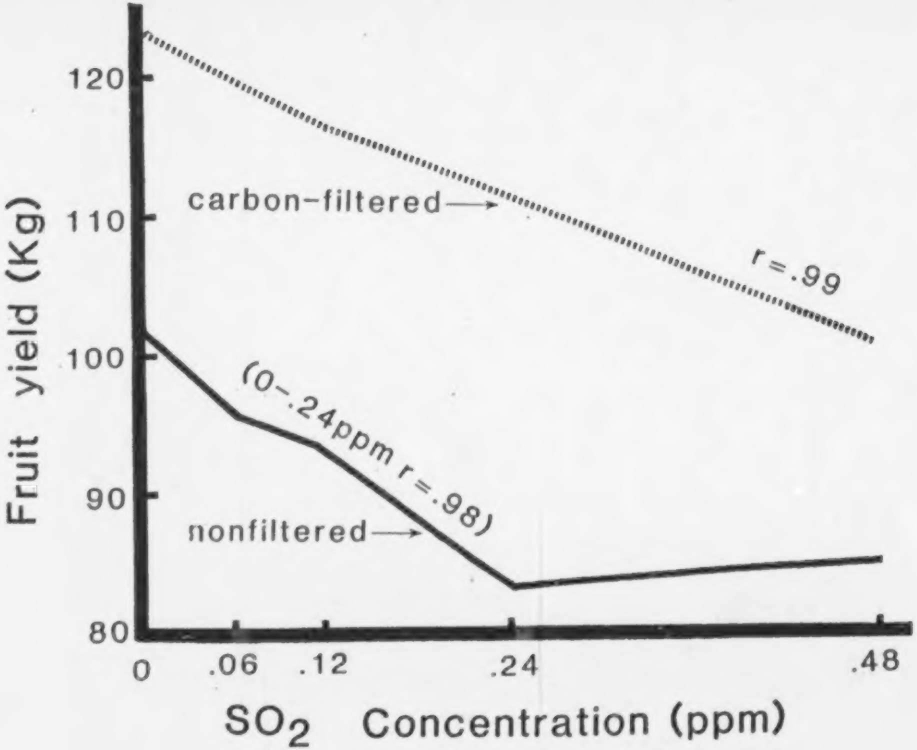


Figure 3. Tomato fruit yields (kg/6m^2) and correlation coefficients in response to increasing concentrations of SO_2 applied (5 hr. day/5days week, total 275 hours) in open-top chambers with either carbon-filtered or nonfiltered air.

Table 1. Effects of photochemical oxidants on growth and yield of 5 crop species grown at Beltsville, Maryland, and the Delmarva peninsula.

Species	Varieties tested each year	Years[a]	Yields as compared chambers with carbon-filtered air	
			Non-filtered chambers	No chambers
	no.		%	%
Potatoes[b]	3.1	1973-77	90	112[e]
Soybeans[c]	4	1973-75	80	101[e]
Sweet corn[d]	4	1977-78	91	93
Snap beans[d]	3.3	1972-76	96	96
Tomatoes[d]	1	1979-80	83	64[e]
Average			88	93

[a] Four replications each year except for tomatoes (3 replications).

[b] Grown at Painter, Va., 1973-75, cooperation Dr. R. E. Baldwin and Mr. Boyette Graves, Va. Tuck and Ornamentals Res. Station; at Georgetown, Del., 1976-77, cooperation Dr. D. Fieldhouse, Univ. Del. Newark; and at Beltsville, MD., 1974.

[c] From R. K. Howell, et al.; grown at Queenstown, Md.

[d] Grown at Beltsville, Md.

[e] Higher and lower values than in non-filtered chambers may indicate chamber effects such as a response to the slightly less light (<10%) or to a temperature increase (<3C°). When skies were overcast (40-50% of the time) temperatures in the chambers were the same as those outside.

Table 2. Effects of mixtures of SO_2 and ozone in NF air on yields of snapbean, 1979.

SO_2 concentration (ppm)	SNAPBEAN YIELD AS PERCENT OF CF (Average of 3 cultivars)	
	CF	NF
0.0	100 A	98.5 A
0.06	-	91.0 A
0.12	-	83.5 A
0.30	84.5 A	55.9 B

Table 3. Effects of mixtures of SO_2 and ozone in NF air on yields of ripe tomato fruits, 1979.

SO_2 concentration (ppm)	RIPE FRUIT TOMATO YIELD AS PERCENT OF CF	
	CF	NF
0.0	100 A	82.9 AB
0.05	-	75.2 B
0.10	-	78.3 B
0.25	77.7 B	68.3 B

Table 4. Effects of mixtures of SO_2 and ozone in NF air on total tomato fruit yields, ripe plus green fruits harvested at the end of season, 1979.

SO_2 concentration (ppm)	TOTAL FRUIT TOMATO YIELD AS PERCENT OF CF	
	CF	NF
0	100 A	95.2 AB
0.05	-	88.0 AB
0.10	-	85.4 B
0.25	90.8 AB	82.6 B

Table 5. Tomato yield losses caused by SO_2 and ambient oxidants, 1980.

SO_2 CONCENTRATION (ppm)	TOMATO YIELD AS PERCENT OF CF[1/] [2/]	
	CF	NF
0.0	100 A	83.5 BC
0.06	-	78.5 CDE
0.12	95.0 AB	75.5 CDEF
0.24	-	67.0 EF
0.48	82.2 BCD	68.5 DEF

[1/] Treatments followed by same letter are not significantly different at P=.05.

[2/] Total yield of ripe fruits harvested each week over a 10-week period when SO_2 was added to the chambers.

Mr. BROWN. Thank you very much, Dr. Heggestad.

Mr. Scheuer, any questions?

Mr. SCHEUER. Well, Dr. Heggestad, your testimony has been very provocative and stimulating.

So much of the polluting is transnational, with Canada receiving about half of their pollution from the U.S. effects, and we in the Northwest United States receive about a quarter of our pollution from Canada.

You talk about this great range of multidiciplinary research activities that are going on now. Would it be possible to develop an integrated program of study of the effects of pollution on crops and forests that would be appropriate for all of these countries with transboundary pollution? Into an overall program the factors that could be studied are both contributing factors and the receiving factors. Then if you set up some type of an enforcement mechanism or some type of cost assessment, the basic data would come from a uniform study whose design and operation would have been accepted beforehand by the countries affected.

Could you see something like that being useful?

Dr. HEGGESTAD. I am sure any setup could be improved upon, and I think there is some cooperation between Canada and the United States in an informal way at air pollution workshops that are held annually, and more and more the Europeans are meeting with us and to some extent we are meeting with them. The technology is changing.

The problems also are somewhat different; for example, in England versus the United States. In the case of sulfur dioxide, they are more concerned—and I think rightly so—about the background of SO_2 increasing. There are many, many sources and a very large area of the country is influenced by the emissions, whereas in the United States generally most of our problems are downwind of a significant source, whether it's a powerplant burning coal, a smelter or some other source. We have high concentrations for 2 or 3 hours and maybe 70 percent of the time there is hardly measurable SO_2. These are two very different kinds of situations.

Now, I saw a study in England last month where they were doing a good job for their situation. They were cleaning the air and adding back pollutants. They were working with sulfur dioxide and nitrogen dioxide. With very clean air they had less plant height growth than when they added a small amount of these pollutants. Where they added a little more pollution the growth was worse than in the clean air. Now, this work is just getting underway. They're putting a lot of funds into the research but are able to work with very low concentrations of these pollutants.

We have tended to avoid the work with low concentrations; 0.06 ppm SO_2 is the lowest I had, because it takes a lot of work and special technology to manage the lower concentrations. We are working now at levels where we have observed effects in nature. We tend to have in this country more of the higher values of SO_2 for short periods of time, so our research orientation is different than in England.

The problem is different in the two countries. I am sure we will see more cooperation and it could be something that we might address to see how far we could go in getting comparable technology at least at some of these locations.

Mr. SCHEUER. You say it costs a lot to address the problem of low pollution concentrations. Can you tell us, in your opinion, what are the annual total figures for crop losses that your research indicates? Can you give us an annual total loss for crop loss?

Dr. HEGGESTAD. I would be glad to make a statement as to what I think but I would put a bracket on it. I haven't felt the data base was adequate. I have said before, losses were about $500 million nationally, but I think now it's closer to a billion dollars.

Mr. SCHEUER. And what is the order of magnitude of the expenditures that would be necessary to reduce that loss significantly?

Dr. HEGGESTAD. One of your other persons here, Dr. Walter Heck, is closer to this than I. He knows more about budget requirements. I would ask that you address that question to him.

We have one field study going on now with soybeans, working with SO_2 and ozone, and we have a good bit of equipment on hand and other things. We feel it takes at least $200,000 a season to get the kind of data needed.

Mr. SCHEUER. You mean $200,000 or $200 million?

Dr. HEGGESTAD. No, at this one location, I'm talking about $200,000.

Mr. SCHEUER. The cost for one crop at one location.

Dr. HEGGESTAD. One crop, one location. That's not representative of the country.

Mr. SCHEUER. Do you have a ballpark estimate?

Dr. HEGGESTAD. No, I'm not prepared to——

Mr. SCHEUER. We don't want to legislate silliness. In other words, if our crop losses are close to a billion dollars and it would cost us $2 billion a year to correct the problem, that is silly. Any time we legislate a remedy, the cost has to be substantially less than the benefit. I am simply trying to get from you just a very rough ball park estimate of what the loss is.

Dr. HEGGESTAD. My feeling offhand would be $2 million oriented to field studies would go an awful long ways in this country.

Mr. SCHEUER. As against a billion dollar possible loss?

Dr. HEGGESTAD. Right.

Mr. SCHEUER. Do you feel, just as a very rough matter of judgment, that it is possible to make significant improvement in the crop losses from pollutant effects for comparatively little money, or very much less than the crop loss caused by polluting effects about which we are doing little or nothing? Is there a sensible basis for proceeding ahead with some kind of a thoughtful remediation program?

Dr. HEGGESTAD. Could I ask you for clarification. Are you concerned with some ways to minimize losses, or some way to get a better handle on it as to what the losses are?

Mr. SCHEUER. Well, both. I think we have to know what the losses are before we go about minimizing them. But we assume, within a rough margin of error, that you're talking about something between a half-a-billion and a billion dollars, and that's a significant loss. Do you think it is possible to make a significant reduction of that loss by a reasonable, moderate, sensible expenditure of funds?

Dr. HEGGESTAD. I really do. I have addressed some of the research needs in my statement and I would not wish to go over them. But I think it addresses this kind of question.

The problem is getting more adequate information on what the losses are, and I have said that the program we have set up now, if it's in place for a few years, will do so much better than has been done before.

The other thing is to minimize the losses. I think addressing it from the standpoint of—I'll call it plant breeding—but an agronomist or horticulturist might only try to be aware that there's an air pollution stress and use the cultivars that we might identify as tolerant and avoid those that we identify as sensitive. That will greatly minimize the losses.

Where I have seen the greatest losses is where growers in Eastern United States inadvertently seemingly got hold of, say, potatoes that were developed in North Dakota or Nebraska, that really never had been exposed to pollutants. They grew all right for a year or two, and then had an air pollution episode and some growers had only half a crop. But that loss didn't have that kind of impact on the potato crop generally in the country, but for those growers it was a terrific thing.

But I think that there are a lot of differences in germ plasm, and we have a manuscript that Dr. Heck has listed. Dr. Reinert, myself, and Dr. Heck have identified what we know about tolerance to air pollutants, mainly ozone and SO_2. We hope the breeders will take this information and make better use of it than at the present time.

Mr. SCHEUER. Thank you very, very much.

Thank you, Mr. Chairman.

Mr. BROWN. Mr. Carney.

Mr. SCHEUR. Mr. Chairman, I have some additional questions and I would ask unanimous consent that I can put them to the witness.

Mr. BROWN. Without objection.

Mr. CARNEY. Mr. Chairman, I thank you.

Dr. Heggestad, on page 1 of your statement you said, "For various reasons injury to foliage is not as common at the present time as two decades ago."

What is this reason for the decrease in amount of injury to foliage, would you know?

Dr. HEGGESTAD. I would be glad to comment.

I think one of the big differences is that we now recognize air pollution injury to leaves. More people know what it is, and with tall stacks and some scrubbers within the stacks, they have reduced these high concentrations near the source. These are factors in reducing the amount of injury. In some cases there has been a significant reduction in sulfur dioxide emissions.

The other thing is, more and more people, with respect to photochemical oxidants, recognize oxidant injury and avoid growing a bean cultivar or sweet corn cultivar, if they have a choice, and they have had a lot of oxidant injury on other cultivars of the same crop.

There is one problem that I would bring to your attention. Where we have been studying oxidants and know that leaf injury was somewhat closely related to yield; that is, a bean cultivar that had very little injury had very little yield loss, whereas one that had a lot of injury had a lot of yield loss. But in a gas mixture situation, we find the cultivar that is very tolerant to oxidant—and this was in 1979—had no lesions on the leaves but it had a yield loss as great or greater than cultivars showing injury. Consequently, we can't count on just looking at the injury. It's a guide for determining when we might have a yield loss and when we don't.

The other thing is, with air pollution stress, ozone and SO_2 at low concentrations—and that's where most of the country is—you get increased senescence, chlorosis, and loss of leaves. Unless you have tools such as we might have with the clean air, or a very good observer, you may not know there is a stress on these plants; yet there is a real stress and the plant is not able to photosynthesize the way it should so there is a yield loss. It's a kind of hidden injury. I really prefer to call it premature loss of chlorophyll and loss of leaves.

Mr. CARNEY. In essense, then, since the Clean Air Act, and since we have improved our air, that is one of the reasons that we have had less foliage damage in the last two decades, and the relationship between crop yield and foliage damage is variable between different plants and we can't identify that.

Dr. HEGGESTAD. It certainly is.

Mr. CARNEY. That brings me to my next question.

Do we have the techniques available and the tools available to properly assess these damages, or are we still going through research and development on the tools to make these assessments?

Dr. HEGGESTAD. We have made an awful lot of improvement in the last 5 years, and we think the technology we have will give us meaningful data that will have broad acceptance. But I feel it is still important that there be some research to look at other ways of getting at this same problem—is there a way of further improving the technology?

Mr. CARNEY. On page 2 of your statement you say:

> We recognize limitations in our efforts to quantitatively assess the impact of air pollutants on crop productivity, especially when differences in yield are less than 10 percent due to treatments.

In essence, are you saying that we can't really get the state-of-the-art down to making that type of assessment below yield differences of 10 percent?

Dr. HEGGESTAD. Well, I think we can get it down, with effort, so we have replications of the same treatment, and then we do these tests more than 1 year, and in more than 1 part of the country to get more of a data base.

Another thing we can do for example with data of Oshima which I passed around and data I have shown here, is to use regression analysis. I think where you get high correlation coefficients—0.99, 0.98—I don't know what the correlation is in Oshima's study, but I'll bet it is 0.97 or something like that—you can't ignore there is some effect at these low doses. This may be true even though from an analysis of variance or some other statistical procedure, it would show no statistical difference. I think we are using more and more the tools that are available to see where the threshold for significant injury occurs.

Mr. CARNEY. So that you feel in the future you can attribute losses of less than 10 percent to a specific source?

Dr. HEGGESTAD. Yes, sir. In the case of snap beans, we have worked for 5 years, and we had 2 crops each year, and our results show that there was a 5-percent average loss for the cultivars we used. I think that is a good figure. In a certain sensitive variety there was a 15-percent loss, but there are not many studies of that kind.

Mr. CARNEY. The National Crop Loss Assessment Network, when do you think that will be in a position to give us the results of assessing the impact of air pollutants?

Dr. HEGGESTAD. Well, weather cooperating and so forth, I would say the results as planned in the next 2 years will go a long ways in providing some data that is not available to you at the present time. I would like to see it even longer. But in 2 years, this year and next year, there should be some very significant data available.

Mr. CARNEY. That is very good.

One other question. We talk about crop losses in terms of dollars. Do we adjust those dollars? Do we take a base line figure, say 1980 dollars, and look at 1980 and 1981 and 1976, or are we looking at the loss to the agricultural industry in those years in the dollars of those years?

Dr. HEGGESTAD. Well, you can see what I have done. I just put on a percentage loss comparing productivity in nonfiltered air with carbon-filtered air. I prefer that to talking about so many grams lost per plant and that sort of thing.

However, in this National Crop Loss Assessment Network there are economists that are interested in helping to plan the research and who are going to handle the research information that they know something about and help to plan. Then I think the dollars will have a lot more meaning than some of the stuff that I have seen.

Now, I'm not sure if I'm answering your question, but——

Mr. CARNEY. I appreciate the predicament you're in. You're not doing the economic assessments on crop loss. But I was just curious because we tend always to put an economic assessment on no matter what we are talking about, so it is vivid in the eyes of everyone present. You talk about dollars and cents, and I was just curious—We talked about a $500 million loss to a billion three, and I was wondering if we were using the same dollar values there. But that is not important. I am sure we can ask that of the economist and not of the scientists when we have that opportunity.

Dr. HEGGESTAD. A colleague of mine, sir, Dr. Heck, is going to talk about that in a little while.

Mr. CARNEY. OK. I am sure we will ask that question.

I would like to thank you for your presentation. It was very informative.

Mr. BROWN. Thank you very much, Dr. Heggestad. We will be back in touch with you.

I would now like to recognize the distinguished chairman of the full committee, Mr. Fuqua, to introduce our next witness.

Mr. FUQUA. Mr. Chairman, thank you very much.

Before I do that, I want to commend you and the Agriculture Committee—and you are also a member of this committee—and Mr. Scheuer, for having these hearings on a most timely and important subject matter. It involves all of us and our food and fiber and I think you have a very excellent list of witnesses here. I again want to congratulate you on the foresight of these hearings.

I am very pleased--and I apologize that I am going to have to leave—to introduce Dr. Al Wood from the Institute of Food and Agricultural Sciences at the University of Florida, who is going to talk to us about forestry and the impacts of pollutants on forestry, which is another very important crop that we have. Dr. Wood is a very outstanding person in the field on the effects of pollutants on various types of crops, particularly forestry. We are very happy to have him here this morning.

I again apologize for having to leave to go to another meeting that I am already late for. I will try to get back.

STATEMENT OF FRANCIS ALOYSIUS WOOD, DEAN FOR RESEARCH, INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES, UNIVERSITY OF FLORIDA

Dr. Wood. I understand, Don. Thank you very much.

Mr. Chairman and committee members, my name is Francis Aloysius Wood. I am dean for research, Institute of Food and Agricultural Sciences, University of Florida. It is a pleasure to be able to make a presentation to this committee about the effects of air pollutants on forests.

My primary goal is to develop a basis for the contention, my contention, that ozone is the major air pollutant threatening our forests at this time in the United States and in North America. Along with that, I will enumerate what I consider to be significant research needs.

Also, I think it is necessary that I explain the 1-page outline that you have. I have been traveling since requested to participate in this hearing and a more detailed statement is being prepared and will be submitted. This is all I could put together by phone.

Mr. Brown. It will be made a part of the record when it is submitted, Dr. Wood. We appreciate what you have done.

Dr. Wood. Thank you, Mr. Chairman.

To begin with, very generally—and I have a number of slides to develop the topic—there are really three or four major pollutants that affect forests—sulfur dioxide, hydrogen fluoride and other forms of fluoride, ozone, the most important oxidant, and other oxidants like PAN, peroxyacetyl nitrate, oxides of nitrogen, and so on.

You could find a long laundry list of other pollutants that at one point in time and in one location might have caused injury, but these were usually local kinds of situations. These four pollutants are generally considered to be the major ones affecting forests.

An evaluation of the overall situation with respect to compounds such as PAN indicates that in general, at least, our Eastern forests are not susceptible to the concentrations of peroxyacetyl nitrate that exist in our normal urban atmospheres and the rural atmospheres, so one can eliminate PAN, I think, at this point in time as an important toxicant as far as forests are concerned. The same applies to the oxides of nitrogen.

Hydrogen flouride is an important pollutant, but only in relatively local situations involving steel mills and steel manufacturing or high-energy phosphate fertilizer production and so on. Again, in the aggregate, rather small by contrast to the potential damage from sulfur dioxide and, in particular, ozone.

The slides I have, we will begin with this one, illustrate several different points I want to make. First of all, transportation and ozone is associated with that particular source; the generation of electricity, sulfur dioxide is associated with that particular source.

These slides show the impact of sulfur dioxide on plants in particular, and on ecosystems in general. I will show a second series on ozone. For those of you who haven't seen a powerplant for real, this is a view of a powerplant. It uses about 20,000 tons a coal a day and it releases between 500 and a 1,000 tons of sulfur dioxide a day, depending upon the sulfur content of the coal being used. So it is a large one. It has large parbolic cooling towers and 800-foot smokestacks.

The effects that sulfur dioxide can cause are either acute or chronic. The acute effects involve a killing of tissues or necrosis of cells. This is a very sensitive blackberry showing sulfur dioxide injury. It is an excellent indicator that occurs throughout the Eastern United States and is very sensitive.

On hawthorn, we find these kinds of interveinal symptoms. Also, hawthorn is a good indicator and it is highly sensitive.

A view of a black birch and an excellent example of sulfur dioxide injury, and it, too, is quite sensitive. A view of red maple which is not quite so sensitive and possesses a little different kind of symptoms. Balsam poplar from northern Minnesota. Again intervenal killing of cells and tissues, and different in color from the preceding examples but typical of sulfur dioxide injury.

A view of a spoil bank in Pennsylvania showing eastern white pine and Austrian pine severely damaged by a ground level source of sulfur dioxide.

A close up of Scotch pine showing what we call tip necrosis or tip killing, by sulfur dioxide. Notice the uniformity of symptoms from needle to needle. This is one technique or one important criterion in diagnosing air pollution injury. Diseases caused by fungi, bacteria, microbes, and so on usually cause cause a nonuniform symptom pattern. Pollution symptoms are usually uniform in one way or another. This is an eastern white pine with tip necrosis caused by sulfur dioxide.

This is an eastern white pine injured by stack emissions from a powerplant. Again notice the uniformity of symptoms over the plant.

Here is a view of Douglas fir, with tip necrosis caused by sulfur dioxide.

In looking at the effects of sulfur dioxide, one must realize that powerplants represent the most important single source in this country. In trying to develop a picture or an understanding of the impact of emissions from a powerplant, one needs to know the relationship between stack height, amount of pollutant emitted, and wind direction. I want to develop that series of thoughts with the next few slides.

These slides do not involve sulfur dioxide, but are just used as an example of what a ground level source—if you had a powerplant without a stack, can or could do. This is a very small ground level source of hydrogen chloride, the burning of insulation, of polyvinyl chloride from copper wire. As you can see, it is at ground level.

Northeast of that, just 50 yards, everything was dead in this northeastern forest.

Out about 400 or 500 yards we begin to see some of the maples and beeches surviving, but not very well. Out 7 miles, the only plant species we could find any symptoms on was black cherry, which turned out to be very sensitive. So as one move away from the ground level source, the amount of injury and severity of it and the number of species affected declined.

When examining the impacts of air pollution on a forest ecosystem, you realize we are looking at diverse community of many different species. These species vary in their sensitivity to pollutant, and within a species there is a lot of variation in response from one plant to another to a given pollutant. So it is important to keep this in mind as one thinks of a forest community and the impact that a pollutant might have.

Now, thinking in terms of powerplants, if we had a powerplant with a ground level source, we would have utter devastation. We do not. The trend has been toward taller stacks. Tall stacks elevate the source and effectively reduce ground level concentrations.

As one increases the stack height from zero to 300, 400, or 500 feet, depending upon the terrain and so on—and I'm thinking primarily now of a rolling or level terrain—but when one gets into the 400- to 500 foot stack height category, instead of having a continuous area of injury, most severe close in and least severe farther away, patches of injury develop. The plume comes out of the stack. and carried by the wind direction, and under certain kinds of atmospheric conditions, about midmorning when inversions break up, the plume tends to come down. Wherever it comes down in concentrations high enough, it can cause injury. The result is small areas of injured plants.

With taller stacks, one does not find there areas of injury. There are powerplants in existance in the United States today that have taller stacks, and one cannot find visible evidence of sulfur dioxide injury within 30 miles of such powerplants.

This is a view looking at the various kinds of emissions from powerplants. Dust can be a problem. Dusts, in general, are not very toxic to plants unless they occur in heavy loads on the plant's leaf surfaces. Also we have excellent facilities and the technology such as electrostatic precipitatorsfor cleaning up dust problems.

This is a view of a powerplant in the four corners area of the Southwest where the precipitators were not functioning. You can see the massive dust problems associated with this plant. I took this photo about 7 or 8 years ago and this problem has since been cleaned up, but it gives you an idea of what the dust problem could be if we did not have precipitators.

The point I want to leave you with here is that, in general, we do not have a dust problem associated with powerplants in terms of negative impacts on vegetation, forest vegetation. So the tall stacks, I think, are a major reason why we can develop additional coal-fired powerplants, increase our energy supply, and do it with a minimum amount of impact on the environment.

If one studies the forests around such powerplants, one will find, as I have said, very little evidence of visible injury, symptoms, and so on. One will find elevations in the the sulfur levels of vegetation, one, two to three times the background. We do not know what that increase in background sulfur level in the foliage and in the soil means. We need additional research here.

By elevating the source, we disperse the sulfur dioxide and other pollutants to other areas but at lower concentrations and, of course, it probably does or at least it may contribute to acid precipitation. The exact amount of the contribution and the form of contribution relative to other contributions to acid precipitation and the impact of acid precipitation on forests are yet to be determined.

This just happens to be a view I have of a 1,000 foot smokestack. If you have never looked up at one, it is rather breathtaking if you like smokestacks.

Smokestacks increase the buoyancy of the plume. Here is an example of this phenomenon. The plume you see coming out of a cooling tower beneath an inversion in the mountains in Pennsylvania. The heat of the plume carries it up through the inversion. This is one of the positive effects of tall stacks.

Now, it is impossible to study in the field, in the United States, in most areas, the impact of powerplants on vegetation without having the study confounded by ozone. Ozone, O3, oxygen 3, atoms.

Ozone occurs naturally. We know it occurs in the outer atmosphere. We know that it can occur at ground level as a result of electrical storms and so on. But we also know that the major source of ozone at the Earth's surface today is what we call photochemical. It is derived from pollutants that are released into the atmosphere by activities of man and some natural phenomena. The automobile releases hydrocarbons and oxides and nitrogen; powerplants release among other things oxides of nitrogen, which are involved in the formation of ozone. Here is one of the simplest reactions. Nitrogen dioxide in the presence of energy or light, ultraviolet light, may disassociate to NO and atomic oxygen, which may then, depending upon equilibrium of the reaction, form ozone. This is just one of many reactions that can result in ozone formation.

We find ozone on days like today. This is a beautiful day for such a hearing. We have a large, stable high in the eastern United States, a very smoggy, hazy day, and just think of all those auto exhausts going into the atmosphere being cooked by the Sun and being converted to ozone and an array of other compounds, many of which are quite toxic.

This is a view of Beverly Hills in California and the smog of California.

This is a view of that same smog cloud at Riverside, which is 60 miles to the east. The point is, the smog that develops over Los Angeles doesn't remain there. It drifts out to the countryside, generally to the northeast, to San Bernadino, and into the San

Bernadino Mountains. There are species of pine, such as ponderosa pine that are sensitive to ozone in thè mountains. This is a view of ponderosa pines in that region that were uneffected by the smog (ozone) which was produced over Los Angeles and drifted out into the mountains.

This shows a closeup view of the yellow mottling that occurs on the older needles of ponderosa pine in that area. We now know on older needles of pines similar symptoms develop following exposure to ozone for a period of time. As a result of some excellent work done at the University of California in Riverside, at Berkeley, and the U.S. Forest Service in southern California, we know that the kind of damage I am showing you now occurs as far as 100 miles northeast of Los Angeles.

This work was initiated back in the early sixties and has been carried on since then. In the meantime, we have studied the problem in the East.

New York City has smog. Baltimore, Md., may have smog. Washington, D.C., Philadelphia, Pittsburgh, Cincinnati, you name it, they have smog. But that smog is not confined to the cities. In fact, it very often drifts out to the forested areas.

We have learned, since about 1965—incidentally, ozone was demonstrated to be phyta toxicant in 1958, so we have not known it as a plant damaging pollutant for very many years, 1958. In the mid to late sixties and early seventies, we learned what ozone symptoms on broad leaf species looked like. There is a stippling of the upper leaf surface of the older leaves. This is a view of the black cherry twig. The youngest leaves occur at the tip of the branch, and the older leaves at the base. This stippling, this kind of symptom is what ozone does to many different plants. I will show you some examples now.

This is a closeup of the same. This is ozone stippling on a sycamore leaf, a closeup. This is an insect feeding injury, the light area. The dark spots are stipples. They are only apparent or visible on the upper surface of the leaf.

Next is tulip poplar or yellow poplar, showing a very severe ozone stipple. If you turned such a leaf over you would not see any injury on the lower surface sassafras with ozone stipple.

Eastern white pine, showing tip necrosis, ozone-type injury. Eastern white pine, in an old field. These trees were all the same age, but are different sizes largely as a result of their ozone sensitivity. The sensitive ones are smaller.

This is an Eastern white pine. We call these chlototic dwarfs. This tree was 10 years old but highly susceptible to ozone. The older needles fall (drop) and the current needles as you can see are yellow and not very efficient photosynthetically so the plants do not grow very fast.

This is a view of Independence National Historic Park. All the slides I have shown to this point, the symptoms, were found in the wilds of Pennsylvania, Maryland, West Virginia, Ohio, and New York and so on. These three slides are on downtown Philadelphia.

The first is a view of Independence National Historic Park. This is ozone injury on a basswood that had been planted recently. Close up view of the stipple on basswood. This is an overall view of that tree which had been brought into the park approximately 4 years earlier. That is the end of the slides, incidentally.

That particular tree had been brought into the park as a part of a reforestation and beautification effort. It turned out to be highly sensitive to ozone and was lost, as were many other species.

The ozone problem in the metropolitan areas of the United States, as well as the rural areas, has increased with the increase in automobile use. This increase has occurred over 40 to 50 years. Thus, the ozone pressure on the population has been slowly increasing, and as it has, the most sensitive individuals have been lost. So it is possible to go into a city environment where the ozone levels are relatively high, and if you look at sensitive plants that have been there for some time, quite often you will not find symptoms. But if you look at recent plantings, gardens or recent landscapes, you will find ozone symptoms if ozone-sensitive species are among those planted.

Back to the general problem of the nonurban forests. On a given year, this is the kind of scenario you can expect on the forests in the Eastern United States, right about now. Incidentally, I spent the last 3 days in Pennsylvania looking at forests. The ozone symptoms are just beginning to show on sensitive species. By the first of August, the ozone-sensitive species throughout the Eastern United States will show significant symptoms and defoliation will have already begun. It happens every year to a greater or lesser degree, depending upon the nature of the air pollution episodes and the environment, whether or not it is favorable.

The problem, in my opinion, has been worsening. There are data that indicate reductions in tree growth associated with this, but these data are meager. I think there is little question that ozone is the most important problem confronting our forests today, and when you look at the major metropolitan areas and realize that it is possible for ozone or the ozone cloud, the smog cloud, to be carried 100 to 150 miles in one direction or another from these sources, most every forested area in the Eastern United States is a potential target, and at one time or another through a given growing season may experience one or more ozone episodes.

We looked at some 1978 data recently on monitored levels of ozone in western Pennsylvania. The national standard to protect vegetation is 0.12 parts per million for 1 hour, not to be exceeded more than once in a given year. It was exceeded well over 100 hours in 1978, with concentrations as high as 0.19 parts per million, which is a very high ozone concentration.

As far as more specific research needs, we need to know more about the impacts of ozone on forest productivity. We do see symptoms most everywhere, at least in the East.

We need to know more about the effects of sulfur accumulation in ecosystems associated with powerplants. We need to know more about ozone-SO_2 interactions, as Dr. Heggestad has indicated. We need a better understanding of powerplant contributions to the acid precipitation problem, and a better understanding of the effects of acid precipitation.

I would be happy to respond to questions.

[The prepared statement of Dr. Wood follows:]

IMPACT OF COAL BURNING POWER PLANTS ON FORESTS

My name is Francis Aloysius Wood and I am currently Dean for Research, Institute of Food and Agricultural Sciences, University of Florida. I have a B.S. degree in Forestry and a M.A. in Botany from the University of Missouri and a Ph. D. in Plant Pathology from the University of Minnesota. I was a member of the faculty of the Department of Plant Pathology of the Pennsylvania State University from 1961 to 1972 and Head, Department of Plant Pathology, University of Minnesota from 1972 to 1977. One of my primary research interests has been the effects of air pollution on vegetation, and in addition, I have consulted for a number of industrial and governmental organizations. I received an Outstanding Alumnus Award from the University of Missouri in 1979.

In discussing the impact of coal burning power plants on forests this morning, I will include the following topics:

(a) Characteristics of forest ecosystems (natural ecosystems).

(b) General characteristics of coal burning power plants.

(c) Types of pollutants emitted from coal burning power plants.

(d) Definition of a few pertinent terms.

(e) Types of symptoms caused by power plant emissions.

(f) Patterns of effects around coal burning power plants in relation to stack height and prevailing wind direction.

(g) Short term versus long term effects. This would include long term effects such as growth reductions and the accumulation of sulfur in foliage.

(h) Relationship of the effects of areawide ozone problem to effects of power plant emissions.

(i) Impact of ozone on forests with emphasis on eastern forests.

(j) Comparison of and summary of the impacts of sulfur dioxide and ozone on forests with a statement of our current knowledge and future research needs.

Mr. **BROWN**. Thank you very much, Dr. Wood. That is an extremely informative statement. I am glad that you included my district in describing some of the problems in southern California.

Mr. Carney?

Mr. **CARNEY**. Thank you, Dr. Woods. It's always a delight to have a 'Gator here. I noted that in the beginning you said you didn't have a chance to prepare your testimony. I would love to see you in action when you are prepared, because your testimony was quite informative.

A couple of questions I do have of you. You said the visible evidence of injury from powerplants with tall stacks is negligible from a sulfur dioxide level. Do we find evidence in the air where you don't have that visible plant disturbance, but can we measure higher imputs of sulfur dioxide in the air near those plants with the higher stacks?

Dr. **WOOD**. In comparison to background?

Mr. **CARNEY**. Yes.

Dr. **WOOD**. Yes, you can. But in most instances, most data I have seen in the last 10 to 15 years from around powerplants with tall stacks, the national standards are seldom, if ever, exceeded.

Mr. **CARNEY**. I see.

You stated PAN and nitrogen oxide do not have that much of an effect on our forests. Would that hold true, too, for our crops, other than forests?

Dr. **WOOD**. No. There are certain vegetable crops that are highly susceptible to PAN.

Mr. **CARNEY**. So we have to be concerned with those as well?

Dr. **WOOD**. Yes.

Mr. **CARNEY**. Powerplants are the largest contributor of SO_2 in the air. What is the largest contributor for ozone?

Dr. Wood. In general, I would have to say the automobile. Ozone can be derived from nitrogen oxides, regardless of where they come from, of course, and they also are emitted from powerplants. But I don't think there's any doubt that transportation and specifically the automobile is the largest source of those pollutants which contribute to the development of ozone.

Mr. Carney. I asked the previous witness about economic impact, and I know, being a scientist and not an economist, it was tough for him to answer those questions. Perhaps you are in that same predicament.

But do you have any sort of handle from your colleagues or from your own research as to the economic impacts to forestry specifically of ozone and sulfur dioxide?

Dr. Wood. Not really. I think we are farther away from any kind of even an educated guess than we are with other agricultural crops. I guess that sounds like a copout.

But I would be interested in what Dr. Page has to say later on this morning. We have talked a lot about the development of mechanisms for assessing the impact and thereby determining the economic loss. However, with the exception of the study that was done in southern California, where detailed measurements of forest productivity have been made—and they were converted to dollars and so on—and attempts were made to estimate the esthetic losses, studies of the impact of ozone on forests have not been made.

Here in the East we just don't have the information. We see this background of symptoms out there, as I said, every year. I do not know.

Mr. Brown. Will the gentleman yield?

Mr. Carney. I would be glad to yield, Mr. Chairman.

Mr. Brown. The study that Dr. Wood refers to in southern California determined several problems stemming from the economic characteristics of the forest. A good part of the value of the forest is recreational in southern California, and it is almost impossible to quantify the loss of a recreational asset of that sort.

The timber is not a major factor, although there are timber losses also, but these are hard to measure because in many cases they actually cut lumber from the dead and the dying trees and it may show a temporary increase in the economic output as far as the timber production is concerned, but measured against the loss of recreational value, of course.

Mr. Carney. The chairman makes a good point. Not talking to this type of damage, but in the east coast of the United States this year we are faced with the gypsy moth, particularly up in my area, and I spent a week in the forest vacationing this last week and I couldn't believe the damage and loss to the recreational facilities caused by the gypsy moth this year. It was absolutely incredible. That is a good point.

It is very difficult to put an economic assessment on what we are talking about today, but unfortunately, sometimes that is the only thing that does move Congress and I am trying to do that.

Thank you very much, Dr. Wood.

Mr. Brown. Mr. Sensenbrenner?

Mr. Sensenbrenner. Dr. Wood, I have one brief question.

Do you know if there are any scientific studies that have been published that measure the effects of a mandatory automobile emission inspection program with reduced ozone levels and the effects of those reduced ozone levels on the forests?

Dr. Wood. I don't know of any studies specifically set up to do that, no. One of my colleagues may, but I do not.

Mr. Sensenbrenner. Thank you.

Mr. Brown. Dr. Wood, could you say a word or two about the adequacy of the monitoring program as a whole to modify the developing of this pollutant situation throughout the United States? Do we have an adequate system in place to allow us to continue to evaluate what is happening here, or is there a need for some additional effort in this particular area?

Dr. Wood. I think that in the case of the acid precipitation situation, an adequate network for monitoring is in the process of being developed and I think we are in pretty good shape there, although there is a long way to go.

As far as ozone is concerned, there isn't any overall coordinated effort such as that associated with the acid precipitation program. If one could pull together the myriad of different kinds of studies, made by many different utility companies, State agencies, and so on, we may have an effective network, but as I say, these monitoring efforts are not coordinated. I think if those data could all be somehow accessed that we might have a pretty good record. It would be a mosaic kind of thing as it came out, but I think this needs to be assessed, exactly what do we have that we can count on in the long term.

As you know, the major problem with monitoring is that it is costly and it takes a lot of time to get information. If we had good records of the chemistry of precipitation for the last 30 years, I mean good, reliable records, we would know a lot more than we do today about acid precipitation, but to get 30 years worth of data we are going to have to wait 30 years.

Mr. Brown. There is another problem that may or may not be important—I don't know—but we have had reports from utilities indicating that in many cases these companies do have comprehensive monitoring networks related to their own system, but they are not really enthusiastic about releasing data which may result in an adversarial action against them. I think this problem can be resolved, but as you indicate, we apparently haven't done a good job of resolving it so that we can integrate some of the sources of data that are already available.

Dr. Wood. Right. That problem has been solved in some States. In Pennsylvania, for example, a lot of the utility monitoring records are supplied to the State and are a matter of open record. It is done as a part of the compliance program there.

Mr. Brown. I think that is a good step. I have no further questions this morning. Your testimony has been excellent and we do appreciate it and look forward to hearing more about it.

Dr. Wood. Thank you.

Mr. Brown. Our next witness this morning is Dr. Jay S. Jacobson of the Boyce Thompson Institute of Cornell University.

Dr. Jacobson, we are very pleased to have you here this morning and look forward to your testimony.

[The biographical sketch of Dr. Jacobson follows:]

VITA

Name	Business Address	Home Address
Jay S. Jacobson	Boyce Thompson Inst. Tower Rd. Ithaca, NY 14853 607-257-2030	420 Sheffield Rd. Ithaca, NY 14850 607-277-3541

Education

B.S.	Cornell University, 1955	College of Agriculture
M.A.	Columbia University, 1957	Department of Botany
Ph.D.	Columbia University, 1960	Department of Botany

Positions

Plant Physiologist	1978 - current	Boyce Thompson Institute
Plant Ecologist	1977 - 78	U.S. Department of Energy
Plant Physiologist	1970 - 77	Boyce Thompson Institute
Assoc. Plant Biochemist	1960 - 70	Boyce Thompson Institute
Teaching Assistant	1959 - 60	Columbia University
Research Fellow	1955 - 59	Columbia University

Areas of Scientific and Professional Interest

Agriculture
Plant Physiology
Air Pollution
Analytical Chemistry

Research Experience

Response of agricultural crops to acidic precipitation
Response of vegetation to atmospheric ozone and sulfur dioxide
Use of plants as indicators of air pollution
Monitoring of chemical composition of rain and atmospheric ozone
Measurement of fluorides in air and vegetation
Physiological effects of fluorides on plants

Membership in Scientific Societies

Air Pollution Control Association
American Chemical Society
American Institute of Biological Sciences
American Institute of Chemists
American Microchemical Society
American Society of Plant Physiologists
Association of Official Analytical Chemists
Federation of American Scientists
New York Academy of Sciences
Society of Sigma Xi

Appointments and Committees

Associate Referee for fluorine in plants, Association of Official Analytical Chemists
Center for Environmental Research, Cornell University (adjunct)
Center for Environmental Toxicology, Cornell University (adjunct)
Editorial Board, Journal of Environmental and Experimental Botany
Executive Committee, National Atmospheric Deposition Program
Governing Board, North Carolina State University - EPA Acid Precipitation Program
Graduate Faculty, Field of Environmental Quality, Cornell University
Halogen Subcommittee, Intersociety Committee on Ambient Air Sampling and Analysis
TE-2 Agriculture Committee, Air Pollution Control Association
Terrestrial Impact Assessment Work Group, U.S. - Canada Transboundary Air Agreement

STATEMENT OF DR. JAY S. JACOBSON, BOYCE THOMPSON INSTITUTE, CORNELL UNIVERSITY

Dr. JACOBSON. Thank you very much, Mr. Chairman.

I have had the pleasure of presenting testimony before these joint subcommittees previously and I appreciate the opportunity to do so again. I realize the importance of these hearings and the ones that will follow, and particularly their relevance to reauthorization of the Clean Air Act.

My testimony will attempt to be brief and to the point. I will make a series of statements and then I will attempt to provide evidence for those statements. I will give my interpretation of the reliability of that evidence and also my opinion about the research needed. The opinions I am expressing in this testimony are not those of any agency, public or private, nor are they those of the nonprofit research institute for which I work, Boyce Thompson Institute, nor are they those of my colleagues. They are my own individual opinions.

The first statement is that agricultural crops in many portions of the United States are exposed repeatedly to ozone concentrations that may exceed the current national ambient air quality standard during the growing season.

The evidence for this statement comes from data collected from 475 sites in 181 counties across the Nation in 1979. This information showed that 59 percent of the counties with adequate data east of the Mississippi had one or more sites exceeding the national ambient air quality standard for ozone; 48 percent of the counties with adequate data west of the Mississippi had at least one site exceeding the standard. The State with the greatest number of sites exceeding the standard was California. In the East, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, and Maryland were among those States with sites exceeding the ozone standard.

What is the reliability of this evidence? The reliability of air quality monitoring data has improved considerably in recent years due to efforts of the EPA. It is the not the reliability of data that is in question, but relevance to the agricultural situation that I question. Most air quality data, including that for ozone, is collected in urban and suburban areas. We do not have precise information on the exposure to ozone of wheat, corn, soybeans, or other crops. We have no basis for judging whether ozone concentrations in farm and forested areas in this country are increasing or decreasing, or whether the geographical pattern of exposure to ozone is changing or will change as our patterns of fuel utilization change.

Without specific information on air quality in agricultural areas, precise estimates of the economic cost of ozone to agriculture cannot be made.

Therefore, the research needed: State agencies should be urged to establish a limited number of air quality monitoring sites in the major crop-growing regions of their State. Careful attention should be paid to the EPA quality control regulations for air monitoring sites.

My second statement: Vegetation is exposed to rainfall with concentrations of sulfuric and nitric acids that produce pH values ranging from about 3 to 5½ in the Eastern United States, while the pH of rainfall in the Western United States generally ranges from 4½ to 6½.

What is the evidence for that statement? Data from the national atmospheric deposition monitoring program network that contains more than 70 operating sites in 32 States has provided evidence for this statement. Further proof concerning the acidity and chemical composition of rainfall is available from several other monitoring networks that have operated within individual regions of the country.

What is the reliability of this evidence? Information on atmospheric deposition often is expressed as annual averages which mask considerable variability. The composition of rain and snow varies within events, between events, among seasons, and between sites within a region. Sites vary in these networks according to whether there are or are not local sources of pollution. So there is some considerable uncertainty about the comparability of data within these atmospheric deposition monitoring networks.

The national atmospheric deposition monitoring program network is currently attempting to improve quality control and site classification. This effort is expensive but extremely important because it will increase the chances of detecting changes in composition of precipitation with time and between regions of the country.

So, research needed: The effort to classify the NADP monitoring sites and raise the level of quality control should be supported and encouraged.

Statement 3: Ozone is a powerful oxidizing agent that reacts with many compounds that have biological significance.

What is the evidence for this statement? The evidence is so overwhelming, it has been established in so many different laboratories throughout the world over a period of the last several decades that it is hardly necessary to provide you with details of this evidence, so I will move on to a portion of this section.

In decades of research at many different laboratories it has been determined that some of the plant species at greatest risk to ozone include alfalfa, bean, sweet corn, lettuce, spinach, oats, radish, soybeans, potatoes, and tobacco. Other testimony that you have heard this morning from Dr. Heggestad and will hear from Dr. Heck will provide additional information on the effects of ozone on crops, as well as the information provided by Dr. Wood.

Some estimates of economic losses will be provided soon by Dr. Page.

My only additional comment on this subject is to provide you with a comparison of recent estimates of economic losses to agriculture by air pollution, mainly ozone, compiled from the scientific literature. If you would refer to table 1, the next to last page in my testimony, you will see that there is a very brief comparison of the estimates that are available concerning economic losses to agriculture in the United States. There are three nationwide estimates. There are four available from California. I have not included the estimates that will be provided to you by Dr. Page shortly.

One of the most obvious points in this table is that there are tremendous ranges in the estimates of economic losses, even for the same regions. Why are there these apparent discrepancies? There are a number of reasons that are important to understand. Different procedures were used to satisfy different objectives in carrying out these studies. Some of the main differences in carrying out economic estimates are the following:

There are different categories of crops considered.

There are different crops species that are considered.

There are different years of estimates.

There are different methods used to estimate air quality, and the type of dose response function used, or its surrogate, differs from one study to another.

There are different market values of crops.

I could go on, and I am sure Dr. Page could provide additional explanations of how these economic estimates are performed in different ways leading to widely varying results.

So, what is the research needed, then? We need to better identify the appropriate measures of air quality that are relevant to crop yield reductions from data taken in agricultural areas of the country. We need to derive better dose response functions for effects of air pollution on yield under field conditions. This is what the national crop loss assessment network is attempting to do.

Finally, we need to better analyze and compare the different approaches and procedures used for monetarization of yield losses.

The fourth statement: In regions with low ambient ozone concentrations, exposure of certain crops to acidic precipitation may be beneficial due to the nutritional contribution of nitrogen and sulfur in rain.

What is the evidence for this statement? Research at several of the laboratories performing research on this subject, including the Boyce Thompson Institute, Brookhaven National Laboratory, Corvallis Environmental Research Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory have demonstrated that applications of simulated acidic rain can increase the growth and yield of some crops under some conditions.

In apparent opposition to this, however, tests at these same laboratories have demonstrated that decreases in growth and yield of crops also can occur. This appears to be a contradiction. The response of crops to simulated acid rain may depend on the species of plant, obviously, and the particular chemical composition of rain, but in addition to that, the response may also depend on the soil conditions, the environmental conditions, and the particular cultural factors that we use to grow that crop. The pattern of rainfall, the developmental stage of the plant at which time the rain occurs, and the presence of other pollutants such as ozone also appear to influence the occurrence of beneficial and harmful effects of acid rain.

What is the reliability of this evidence? Well, if you believe that all plants should respond in exactly the same way under all conditions, the above evidence appears to be contradictory. When you understand that plants, just as people, respond differently under different conditions—they respond to their total environment; not just to rainfall or the chemical composition of rainfall—then these results appear quite reasonable.

The number of laboratories involved and the diversity of approaches that they have used in their studies lends further credibility to these results. However, there are many questions that we are not able to answer with certainty.

Which crops are most susceptible to acid rain? We are not yet sure.

How much of an increase in rainfall acidity can be tolerated before reductions in yield occur? We do not yet know.

How significant in quantitative terms is the benefit gained from nitrogen and sulfur in rain? We are not yet certain of the quantitative benefits.

We know that patterns of energy generation and fuel usage will change during the coming decades, but we don't know the extent to which crop productivity will be affected by changes in the deposition of substances from the atmosphere.

What is the research needed? If it is important to know the answers to these questions, then it is obvious that we should continue to support a diversity of experimental approaches on this important topic.

Statement 5, and I believe this is my last statement: In regions with high ambient ozone concentrations, exposure of crops to both ozone and acidic precipitation may intensify the injury caused by ozone.

What is the evidence for this? An intensive experiment was performed at Boyce Thompson Institute in which field-grown soybean plants were exposed to combinations of ambient ozone and simulated acidic rain in open-top chambers for one growing season. At the end of the experiment, measurements were made of the dry mass of leaves, stems, pods, and seeds. Measures of seed quality also were taken. Two of the most striking results in this experiment were that both the mass and number of soybean seeds were reduced by exposure to ambient ozone—this is concentrations of ozone that existed in Yonkers, N.Y., at the time that Boyce Thompson was in Yonkers—and exposure both to ozone and simulated acidic rain at pH 2.8 produced a further decrease in mass of soybean seeds. This is with field-grown soybeans. Experiments performed with greenhouse-grown plants at Oak Ridge National Laboratory also indicated that there may be an interaction between ozone and acid rain on plants.

What is the reliability of this evidence? Conclusions drawn from the results of a single experiment must be viewed as hypothetical until they are validated by additional research. The above statement then needs verification in several ways.

Research needed: First, the experiment needs to be repeated utilizing different approaches and different patterns of ozone and acid rain in order to generalize results from one specific set of conditions, those used in that experiment, to the variable conditions that occur in the field.

Second, the experiment needs to be performed with a variety of crops to determine whether the combined effects of ozone and acid rain are crop-specific or whether generalizations can be drawn for whole categories of crops.

Third, the test needs to be performed at different locations and over several growing seasons to determine whether the effects occur under different soil and different climatic conditions.

The approach that will provide the most conclusive evidence—and this is true for many other areas of our research—is for several laboratories to combine efforts in a joint attack on the problem.

Thank you very much for this opportunity to testify.

[The prepared statement of Dr. Jacobson follows:]

TESTIMONY OF DR. JAY S. JACOBSON

Boyce Thompson Institute
Ithaca, New York 14853

Before the

Subcommittee on Natural Resources, Agriculture Resarch
and Environment of the House of Science and Technology Committee

and the

Subcommittee on Department Operations, Research, and Foreign
Agriculture of the House Agriculture Committee

Joint Hearing
Rayburn House Office Building
July 9, 1981

Statement 1.

Agricultural and horticultural crops in many portions of the U.S. are exposed repeatedly to ozone concentrations that may exceed the current National Ambient Air Quality Standard (NAAQS) during the growing season.

Evidence

Data collected from 475 sites in 181 counties across the nation in 1979 showed that 59% of the counties with adequate data east of the Mississippi had one or more sites exceeding the NAAQS. 48% of the counties with adequate data west of the Mississippi had at least one site exceeding the NAAQS. The state with the greatest number of sites exceeding the standard was California. In the east, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania and Maryland were among those states with sites exceeding the standard.

Reliability of Evidence

The reliability of air quality monitoring data has improved considerably in recent years. It is not reliability of data but relevance to the agricultural situation that is questionable. Most air quality data are collected in urban and suburban areas. We do not have precise information on the exposure to ozone of wheat, corn, soybeans, or other crops. We have no basis for judging whether ozone concentrations are increasing or decreasing, or whether the geographical pattern of exposure to ozone is changing or will change as out patterns of fuel utilization change. Without specific information on air quality in agricultural areas, precise estimates of the economic cost of ozone to agriculture cannot be made.

Research Needed

State agencies should be urged to establish a limited number of air quality monitoring sites in the major crop growing areas of their region. Careful attention should be paid to EPA quality control regulations for air monitoring sites.

Statement 2.

Vegetation is exposed to rainfall with concentrations of sulfuric and nitric acids that produce pH values ranging from about 3 to 5.5 in the eastern U.S. while the pH of rainfall in the western U.S. generally ranges from 4.5 to 6.5.

Evidence

Data from the National Atmospheric Deposition Program (NADP) monitoring network that contains more than 70 operating sites in 32 states has provided evidence for this statement. Further proof is available from several other monitoring networks that have operated within individual regions of the country.

Reliability of Evidence

Information on atmospheric deposition often is expressed as annual average values which mask considerable variability. The composition of rain and snow varies within events, between events, among seasons, and between sites within a region. Sites vary according to whether there are local sources of pollution. The NADP network currently is attempting to improve quality control and site classification. This effort is expensive but extremely important because it will increase the chances of detecting changes in the composition of precipitation with time and between regions of the country.

Research Needed

The effort to classify NADP monitoring sites and raise the level of quality control should be supported and encouraged.

Statement 3.

Ozone is a powerful oxidizing agent that reacts with many compounds that have biological significance. Laboratory experiments have demonstrated ozone and its reaction products interfere with the functioning of critical cellular constituents. The physiological processes of photosynthesis, respiration, stomatal function, translocation, and allocation of photosynthate are altered by exposure to ozone. As with most toxic agents, the total dose received by the plant is a critical factor. In decades of research at many different laboratories, it has been determined that plant species at greatest risk include: alfalfa, bean, sweet corn, lettuce, spinach, oats, radish, soybean, potatoes, and tobacco. Other testimony at this hearing will provide additional information on the effects of ozone on crops and some estimates of economic losses resulting from reductions in yield. My only additional comment will be to provide a comparison of these estimates of economic losses to agriculture compiled from the scientific literature (Table 1). Note that, in this table, nationwide estimates of losses are from $121 million to $2.9 billion per year. For California, estimates range from $15 to $45.7 million per year. Why is there such a wide discrepancy in estimates of economic losses?

Different procedures were used to satisfy different aims. Some of the main differences are in the following factors: 1) crop categories considered; 1) crop species; 3) year of estimate; 4) method used to estimate air quality; 5) type of dose-response function used or its surrogate; 6) market value of crops; 7) cost estimated for producer or consumer; 8) consideration of demand and supply elasticity; 9) consideration of secondary impacts (effects of food processors and distributors, farm suppliers) and 10) consideration of annual or cumulative impact over a period of years.

Research Needed

Research is needed on several topics: 1) identification of appropriate measures of air quality that are relevant to crop yield reductions, 2) derivation of dose-response functions for yield under field conditions, and 3) approaches and procedures used for monetarization of yield losses.

Statement 4.

In regions with low ambient ozone concentrations, exposure of certain crops to acidic precipitation may be beneficial due to the nutritional contribution of nitrogen and sulfur in rain.

Evidence

Research at several of the laboratories performing research on the subject including the Boyce Thompson Institute, the Brookhaven National Laboratory, the Corvallis Environmental Research Laboratory, the Argonne National Laboratory and the Oak Ridge National Laboratory has demonstrated that applications of simulated acidic rain can increase the growth and yield of some crops under some conditions. In apparent opposition to this, however, tests at these same laboratories have demonstrated that decreases in growth and yield of crops also can occur. The response may depend not only on the species of plant and the chemical composition of rain but also on the soil, environmental and cultural factors. The pattern of rainfall, development stage of the plant, and presence of other pollutants such as ozone, also may influence the occurrence of beneficial and harmful effects.

Reliability of Evidence

To those who believe that all plants should respond in exactly the same way under all conditions, the above evidence appears contradictory. To those who understand that plants like people, respond to their total environment, not just to one element of it, these results seem reasonable. The number of laboratories involved and the diversity of approaches used lend further credibility to the results. However, we are not able, as yet, to answer with reasonable certainty questions about which crops are most susceptible, how much increase in rainfall acidity can be tolerated before reductions in yield occur, or how significant, in quantitative terms, is the benefit gained from the nitrogen and sulfur in rain? We know that patterns of energy generation and fuel usage will change during the next coming decades. Will crop productivity be affected by changes in the deposition of substances from the atmosphere?

Research Needed

If it is important to know the answers to these questions, then we should continue to support a diversity of experimental approaches on this subject.

Statement 5

In regions with high ambient ozone concentrations, exposure of crops to both ozone and acidic precipitation may intensify the injury caused by ozone.

Evidence

An extensive experiment was performed at the Boyce Thompson Institute in which field-grown soybean plants were exposed to combinations of ambient ozone and simulated acidic rain in open-top chambers throughout one growing season. At the end of the experiment, measurements were made of the dry mass of leaves, stems, pods, and seeds. Measures of seed quality also were taken. Two of the most striking results were that both the mass and number of soybean seeds were reduced by exposure to ambient ozone and exposure both to ozone and simulated acidic rain produced a further decrease in seed number. Experiments performed with greenhouse-grown plants at Oak Ridge National Laboratory also indicated there may be an interaction between ozone and acid rain on plants.

Reliability of Evidence

Conclusions drawn from the results of a single experiment must be viewed as hypothetical until they are validated by additional research. The above statement needs verification in several ways.

Research Needed

First, the experiment needs to be repeated utilizing different approaches and different patterns of ozone and acid rain occurrence in order to generalize results from one specific set of conditions to the variable conditions occurring in the field. Second, the experiment needs to be performed with a variety of crops to determine whether the combined effects of ozone and acid rain are crop-specific or whether generalizations can be drawn for whole categories of crop plants. Third, the test needs to be performed at different locations and over several growing seasons to determine whether the effects occur under different soil and climatic conditions. The approach that will provide the most conclusive evidence is for several laboratories to combine efforts in a joint attack on the problem.

Table 1. Estimates of Economic Losses to Agriculture from Air Pollution (mainly ozone)

Year of Estimate	Region	Crops	Millions of Dollars	Source
1963	U.S.	All crops and ornamentals	121	SRI
1974	U.S.	Field crops, vegetables, fruits, citrus, seed crops	2900	B
1980	U.S.	Tomato, field corn, alfalfa, soybean, hay, etc.	1800	SRI
1963	California	All crops and ornamentals	33.7	SRI
1970	California	All crops	17.5	CDA
1975	Southern California	Celery, tomato, potato, cotton	15	UW
1975	Southern California	Orange, avocado, strawberry, tomato, alfalfa, etc.	45.7	EL

SRI: Stanford Research Institute; B: Brookhaven National Laboratory; CDA: California Department of Agriculture; UW: University of Wyoming; EL: Eureka Laboratories.

Mr. **Brown**. Thank you very much, Dr. Jacobson.

Mr. **Fuqua**. Mr. Brown, can I ask just one question?

Mr. **Brown**. I was just going to recognize you.

Mr. **Fuqua**. Thank you, sir.

That is very interesting and I wonder if the correlation between those types of plants that liked acidic soil more than those who prefer an alkaline type, if that correlation was made in the study that you referred to. Maybe those that prefer an acid soil would respond to acid rain; whereas, those who prefer an alkaline soil would respond in a reverse fashion.

There are also peanuts, for instance, which require a large amount of sulfur as a supplement to the normal fertilizer process. Would that plant respond? I guess it would be in different varieties, which you mentioned, but was that correlation made in the study?

Dr. **Jacobson**. No, sir; it was not. It does need to be made. I think you bring up a very important point: How variable the responses of different crops can be to an individual environmental stress. We do not yet know the answer to that question.

Mr. **Fuqua**. Thank you, Mr. Chairman.

Mr. **Brown**. Dr. Jacobson, some of the members would like to go and make this rollcall. I will continue asking a few questions myself, but I would like to excuse the other members. They will return as quickly as they can. I just want you to understand the stresses that we have around here all the time.

Dr. Jacobson. All right.

Mr. Brown. Dr. Jacobson, each of the witnesses testifying in their own field of expertise and research are gradually accumulating a case that seems stronger and stronger and stronger for the importance of this area and the need for additional research. I assume you would concur in that statement.

Dr. Jacobson. Yes, sir; I would concur, particularly for ozone, because there seems to be unanimity of evidence among the experts that ozone causes more damage to crops and forests in the United States than any other pollutant as far as we now know.

Mr. Brown. I might offer some anecdotal evidence of a nonscientific nature and ask you to comment on it.

In the area of southern California which I represent there is a very high concentration of ozone, as you point out. It has been in existence now for 20 or 30 years and my observation, confirmed by conversations with some of the agriculturalists, indicated that this has probably been a factor in a reduction of the yield on some of our more important crops, such as grapes and citrus, which has not been quantified, but most people that I have talked to have indicated reductions in yield and in quality have been of an order of perhaps 25 to 50 percent, measured in some rough way by the value of the crop, something of that sort, and it is leading to the destruction of a good part of the agriculture in that area.

Does that seem reasonable from your own observation of the situation?

Dr. Jacobson. Yes. My understanding is that there are several important considerations in southern California. One is that there are certain crops that can no longer be grown in certain portions of California, and we have not yet begun to consider what the increased cost of growing crops in regions further from major metropolitan areas is. This also, I believe, has occurred in New Jersey.

The second consideration is that even though a crop may not be on the list of most susceptible plants to ozone, if it happens to be grown in an area of California that has the highest ozone concentrations, such as citrus, there may be a substantial economic loss. We have not yet begun to quantify it because we haven't looked at the crops that are lower on the list of susceptibility of plants. I think this may, indeed, be the situation in California.

Mr. Brown. I know that your research does not encompass this, but obviously as we establish a firmer data base for the adverse impact of ozone on organisms, agricultural crops, this leads to the question of what the effect might be on human beings. Would you concur that the conclusions as established with regard to the adverse effects of ozone on the ecology might lead to certain deductions that it would have similar, varied, and in many cases adverse effects upon human organisms also?

Dr. Jacobson. Sir, I do not believe I would agree with that. It does not necessarily follow that if there are effects of ozone on vegetation, on crops, trees, on ecological systems, that there then must be effects on human beings. There may be greater or lesser effects on human beings. The systems are so completely different.

Mr. Brown. We would need, in other words, a much stronger data base on the human effects as well as on the other.

Dr. Jacobson. Absolutely. Yes.

Mr. **Brown**. I am aware of a number of efforts at measuring the effects of pollutants on the environment. We have referred to the acid deposition studies which have become of a higher priority as we understand the widespread effect. We have the national crop loss assessment program, which is more recent, aimed at the more general effects. We have studies that have been going on for several years now, operated by the Department of Energy, NOAA has a program, EPA, of course, has had a program which seems to be improving in its scientific basis over the years.

The point I am making is that we have a number of different efforts. The question is: Do you feel that all of this constitutes a coherent national program of monitoring and analysis, or is it still a somewhat heterogeneous and uncoordinated system?

Dr. **Jacobson**. I think that is a very important question you are asking. The answer, my answer to it, is that within a discrete area there is integration and coordination. As you indicated, the acid rain monitoring network is well coordinated, but what is not coordinated is the relationships between monitoring for different types of pollutants.

As I indicated in my testimony, we do not have information on ozone concentrations in agricultural areas because there has been major emphasis on human health effects with ozone. But we do have information on the composition of rain in rural areas of the country because the network was set up that way. So we have a difference, and we cannot effectively combine air quality data and rain monitoring data for agricultural and forested areas.

So there is a definite need for improved integration between these large areas of research and monitoring.

Mr. **Brown**. But this problem of improving the comprehensiveness, quality, and coordination of various fragmentary monitoring efforts has caused me some concern now for a number of years and I would like to elicit from you any thoughts as to what steps might be taken and the importance of taking these steps on the basis of your own experience in this area.

Dr. **Jacobson**. I would like to add a bit of historical information because it may have some importance in the future relevant to this question.

Back in the 1960's most of the data on air quality was taken by individual States and it was found that there was a tremendous discordance in the way the information was taken. Different methods were used, different siting criteria were used, the data were reported in different units, sometimes the data wasn't available from one State and was from another. So nationwide programs were initiated in order to make a more coherent information base, and that has improved our knowledge tremendously. I also would say that the quality control regulations imposed by EPA, have improved the quality of our data very much.

The effort of the National Atmospheric Deposition Monitoring Network to improve quality control, which has not found a source of funds as yet, is extremely important for the same reason. So I feel that these technical and scientific criteria of how monitoring should be carried out in an integrated way, in a fashion that will allow us to interpret the information and make comparisons from one State to another, one region of the country to another, one year to another, are absolutely essential, and whatever the mechanism that best achieves those criteria, that is the one that should be used.

Mr. **Brown**. In other words, you feel—if I misstate this, correct me—that a system which could be fairly decentralized, tailored to the specific regional, State, or local needs of the particular agency or institution doing the monitoring, but coordinated in the sense of a common set of standards and an interconnected network of exchanging data might be a workable system in comparison with, we will say, a centralized, nationally organized system which would function throughout the United States?

Dr. **Jacobson**. We are getting at the mechanism for carrying out these monitoring efforts, and I must admit, Mr. Brown, that there has been a tremendous amount of money spent over many, many years by individual groups and agencies carrying out work within individual States and there is no comparability between the data produced. There is information that utilities have developed, that various industries have developed, States, cities, going back several decades, and we cannot effectively use that data. Sometimes it is just not available.

The criteria are availability, comparability, quality control. If that can be carried out by giving more control to the local agencies, then that would be satisfactory. If local agency control will not provide that level of quality control and comparability, then it must be carried out on a nationwide, centralized basis.

Mr. **Brown**. Well, there are certain problems today in establishing new, centralized, coordinated systems in this country, some of them philosophical in nature and some of them economic, for cutting budgets and not expanding them. It seems to me that this research is a matter of such high priority that it is logical to try and combine our diffuse efforts. There should be some opportunities to develop the necessary monitoring networks that would effectively serve our needs at a lesser cost, without necessarily assigning it to EPA and giving them another $10 million to do it with if they could. The network would perform the standardization and coordination function relying upon the efforts of the land grant colleges or existing State air pollution agencies, or institutions of that sort. There are many logical sources of operating funds and personnel at the local level.

Dr. **Jacobson**. How, then, do we control the uniformity of methods that are used by all these different local agencies? How do we assure that they site the monitoring location in a way that will make the data comparable from one to another? There are a whole host of problems that come up.

Mr. **Brown**. Obviously, that problem would have to be resolved through, first, the establishment of this kind of standard, and second, providing the incentives for them to be met. That might be done in the form of matching for those systems which meet the standards.

Dr. **Jacobson**. Yes.

Mr. **Brown**. That is a conceivable way to go about it. I don't know whether it would function perfectly or not.

Dr. JACOBSON. Another problem that we have, sir—and I think I alluded to it—is that we have ozone data at one site and rain chemistry at another, but not both at an individual site.

Mr. BROWN. Well, I am exploring in my own mind, with your help, what the political possibilities are in an uncertain political time.

Dr. JACOBSON. I understand your problem.

Mr. BROWN. Of course, we are focusing here on merely the first step in an extensive process; that is, establishing the data base which is reliable on which we can make judgments. The next category of research, I think would be, having established this data base, to do a more adequate job of determining effects from measurable causes. Here we need a great deal of research, too, according to your testimony and that of other witnesses.

I am interested in whether or not it is feasible and reasonable to develop a system which relies upon the standardized, greenhouse-type of research for effects in which we can, first of all, make sure that the organisms are growing under standard conditions, and then that the input, the precipitation, the atmospheric pollutants, and so on, can be precisely quantified so we can say that under standard conditions, with standardized inputs, we are getting certain results.

This is considerably different than field conditions, albeit both kinds of research are necessary, but we should be able to get to a point where we can correlate greenhouse conditions with field effects. Are we in a position to develop comprehensive research schemes to treat the problem in this fashion?

Dr. JACOBSON. No, sir. My answer would be that we are not, and here is the situation that is faced by the individual laboratories. As you all know, a laboratory may receive a certain sum of money to carry out a certain type of research and decisions must be made about exactly how that research is carried out, which approaches should be used, should a greenhouse approach be used, where a lot of data can be obtained in a relatively short amount of time for a relatively small amount of money, so you can study a lot of crops and get a lot of information.

However, we do not know how to relate that information to yield reductions in the field. Therefore, should the money then be used to carry out strictly a field program where you can only work with a few crops at a time, maybe, depending on the money, one crop, because it is very expensive and very time consuming. You only get one set of data points for a whole year in the field, where you can get many in the greenhouse, but the results are more relevant to what actually happens in farming areas.

So decisions are made at individual laboratories, given limited funds, usually to do research either in the greenhouse or in the field, or perhaps in controlled environment chambers. Rarely are there sufficient funds to carry out research in more than one way, using several approaches at any one individual laboratory, and I am afraid we are going to continue to face that sort of situation.

So the answer is, No, we are not in a really good position to relate greenhouse and controlled chamber results directly to the field except with certain types of crops such as those injured directly on the foliage, and that affects market value, such as spinach or lettuce.

One very important factor here that relates to Mr. Carney's earlier question about whether we have techniques and tools, which is what you are getting at, to assess damage. We asked certain types of questions in the 1960's and performed a certain type of research. In the 1970's the questions changed and we found that the information available from the research of the 1960's was inadequate. So the research changed in the 1970's to meet the new questions.

Now, in the 1980's, we are asking even more difficult questions about economics, cost/benefit ratios, quantitation of dose response functions. The data from the 1970's are inadequate, so we again must improve our tools, improve our approaches, our techniques, our methods, to answer the new, more difficult questions that are being asked today.

So my answer to Mr. Carney's question is, Yes, we need to improve our techniques and tools.

Mr. BROWN. Mr. Scheuer?

Mr. SCHEUER. The hour is getting very late, Mr. Chairman, so I will be very brief. I would like to more or less ask you the question that I asked the prior witness because your outline of the kind of research that has to be done is relevant. It seems to me—and I think this is what Congressman Brown has been referring to—that we need a comprehensive, grand design of research where cities and States and counties and municipalities can all participate, but subject to certain standards and coordinated as if a slice of the pie so that we get a whole pie fitted together.Thus all the research will be consistent with a standard research design that will lead us to conclusions on which we can make public policy.

Hopefully that would be done not only nationally but internationally with all segments contributing what they can do and what they are capable of doing, but coordinated to a consistent, standardized research design.

Do you see that kind of approach as a useful approach? If so, who would design the overall research strategy and the overall research program?

Dr. JACOBSON. I think you are asking a very good and important question and I would agree that further integration and coordination is necessary because it tends to fill in the gaps that inevitably develop when we have uncoordinated projects.

There are additional problems, as I am sure you understand, in carrying out coordinated research programs and it is very important to be aware of the management problems that come into play when you start trying to integrate research from many different laboratories. We have had two problems, two major problems, in carrying out integrated research programs, and that is, some people feel that an integrated research program is merely the sum of a bunch of individual projects put together. That doesn't work. You still end up with a bunch of uncoordinated information at the end.

Where is the cement? The coordination effort itself requires careful consideration and inclusion in the budget; otherwise, it will not happen.

Second, your question gets, I think, at the question of whether the design of the program should come from the top, say from the Federal agency on down, or whether it should come from the bottom, the scientists coming together, designing the program, presenting it to the agency, and then working interactively and iteratively to develop a better program.

There are examples of both programs, and I must say that my opinion is the ones that work the best in the long run are the ones where the scientists are urged, stimulated, required, if necessary, to get together, design the program, and then work together with the agency from the bottom up rather than from the top down.

Mr. **Scheuer**. Can you give us the process? How would you establish an overall grand design? Would these scientists at the State and municipal level get together, establish some kind of a work team or a task force, and then make a recommendation to EPA that this be reviewed? How would we legislate?

Mr. **Brown**. Don't forget the Department of Agriculture.

Mr. **Scheuer**. The Department of Agriculture, or perhaps the National Science Foundation or the National Academy of Sciences? How do you see that process?

Dr. **Jacobson**. I think in part the answer would depend upon the total scope that we are referring to. If we are talking about how are we going to get integration of research in agricultural effects, or are you referring really to a much larger effort—I think I would have to know more about the full scope of what you have in mind.

Mr. **Scheuer**. Well, I would think that one specific study area would be crop effects.

Dr. **Jacobson**. Right.

Mr. **Scheuer**. Crop and forest effects; in other words, growing things. And a whole other set of effects would be health effects.

Dr. **Jacobson**. Correct.

Mr. **Scheuer**. And a third set of effects would be effects on buildings, structures, monuments, and so forth. That, in itself, costs a billion dollars a year or more in damages, or so we have heard in testimony. But let's eliminate that for these purposes and let's eliminate the health effects for these purposes and just talk about the effects on growing things. It seems to me that is a discrete group, both crop and forest.

I take it both of those would be under the jurisdiction of the Department of Agriculture research programs. You might conceivably bring in the Interior Department because of their control over vast public lands and national parks, and whatnot.

Dr. **Jacobson**. Right.

Mr. **Scheuer**. So I can see the necessity of coordinating research effects of four or five different Federal agencies, and of course, dozens if not hundreds of State and municipal agencies.

Dr. **Jacobson**. Right.

Mr. **Scheuer**. I take it you would get a group of scientists who are conducting research in the field, and establish a task force. I suppose you would want these Federal agencies represented on these task forces, and let them make recommendations to the Federal agencies, with some kind of an interagency task force and then I suppose they would recommend to Congress.

I suppose we would set this up and we would provide a little funding for this effort and request them——

Dr. JACOBSON. Planning effort, you mean.

Mr. SCHEUER. Yes, planning effort, to report back to us in a year's time or 6 months' time.

Dr. JACOBSON. There are several organizations that have a number of scientists involved in these research efforts that meet together once or twice a year, and there are several of these organizations that have been in existence for a number of years. It might be possible to go to one of these committees and say to them, "Well, now, here is a certain amount of money for a planning effort to come up with a program that would integrate this and then work together with the agencies," and there are several organizations that have most of the scientists that are involved in research in agricultural effects of air pollution already working together, but only in an informal way at the present time.

Mr. SCHEUER. Excuse me for being naive and ill-informed. Could you list those organizations; tell us who they are?

Dr. JACOBSON. Yes. One of them is the TE-2 Committee of the Air Pollution Control Association. They just had their meeting last month in Philadelphia, and Dr. Heck is a past president of that TE-2 Committee.

Another one is the effects subcommittee of the national atmospheric deposition monitoring program, the acid rain program, has an effects subcommittee.

A third one is, the group that meets annually called the Air Pollution Workshop at which more than a hundred scientists from this country and others get together to present the latest results of their research. Next year the meeting will be in Riverside, Calif., I believe.

Mr. SCHEUER. Has that already occurred this year?

Dr. JACOBSON. Yes. It just occurred recently. It usually is in April or May of each year.

So these are the three that come to mind. Perhaps my colleagues may have other groups that they are aware of that get together and could serve as a focal point for this planning effort.

Mr. SCHEUER. Thank you very much.

Mr. BROWN. Mr. Roberts?

Mr. ROBERTS. I have no questions, Mr. Chairman, other than to perhaps suggest that of all these agencies that take part in this task force we should include farmers and farm organizations.

Dr. JACOBSON. Yes, and farm organizations, I think, should——

Mr. ROBERTS. I said that in a somewhat facetious vein but we have a crop consultant service in Dodge City, Kans., and it is a private enterprise but in terms of supplying my office information about damage to crops as compared to the USDA—I am not trying to point any fingers of blame here—but he is in the field, he talks to the producer in a very friendly fashion. I would hope there could be some task force, Mr. Chairman, for some kind of real producer input with regard to farm organizations, but more especially people in this field. I think we could probably shoot with a rifle there rather than a shotgun.

Dr. JACOBSON. Yes, I would agree with that, and in addition there are the county agricultural extension agents who are usually in close touch with the farmers, looking at the crops throughout the growing season as part of the USDA experiment station network that could be very useful in this, as well.

Mr. BROWN. Thank you very much, Mr. Roberts.

Thank you very much, Dr. Jacobson. Your testimony has been extremely valuable.

Mr. BROWN. Our next witness this morning is Dr. Walter Heck, U.S. Department of Agriculture at North Carolina State University.

Dr. Heck, we can hardly wait for your testimony since several of our previous witnesses have said that you had all the answers.

STATEMENT OF DR. WALTER HECK, U.S. DEPARTMENT OF AGRICULTURE AT NORTH CAROLINA STATE UNIVERSITY

Dr. HECK. I heard them say that, as a matter of fact.

Mr. Chairman, I am Walter W. Heck, research leader of the air quality research program for the Agricultural Research Service of the U.S. Department of Agriculture. I am located at North Carolina State University in Raleigh, and I appreciate the opportunity to appear before you today to discuss the impacts of air pollutants on agricultural productivity.

Several of the areas that I had planned to discuss have been well covered by my colleagues. The slide presentation from Dr. Wood was most helpful. I didn't have one planned, but that laid a lot of good groundwork, as did the earlier testimony by Dr. Heggestad and Dr. Jacobson.

I thought I might highlight some of the areas of my written testimony. The first paragraph is an attempt to outline for you the attachments that I have made to the testimony as a whole. These reflect some of the review articles that I have written or been associated with over the past years. There are two other articles that I think are pertinent to an assessment of the economic impact of air pollutants on agriculture.

The second paragraph highlights pollution sources, and the three pollutants that are most important to the country as a whole: ozone, sulfur dioxide, and nitrogen dioxide.

The third paragraph emphasizes what my colleagues have already emphasized; the importance of ozone in terms of the country as a whole. It is my opinion that ozone alone or in combination with sulfur dioxide and nitrogen dioxide is responsible for up to 90 percent of the air pollution caused crop loss in the United States.

The fourth paragraph is an attempt to impress upon you the importance of understanding the total air pollution system. Anyone dealing with air pollution needs to have some understanding of the emissions and how to use emission data. An understanding of meteorology and atmospheric chemistry associated with air pollution is essential to the understanding of atmospheric transport and transformation.

Current information suggests that long-range transport is a primary cause of peak ozone concentrations in rural areas of the United States, especially areas east of the Rocky Mountains. I think long-range transport is extremely important. At the current time, our understanding of this phenomena is fragmentary. It is important, in my estimation, to understand that we are dealing here with a national issue, not a regional or a State issue. This is something that is sometimes very easy to forget.

Last, in terms of an introductory statement, it is important to understand that vegetation is the most sensitive biological component of air pollution stress from these three gases. It is critical to agricultural production that this fact be recognized and that any air quality standard include an assessment of crop losses.

I then have a section on crop loss assessment. We are in a stage where we don't really have a good handle on economic losses, but a lot of work has been done over the last 20 years. In terms of the impact of ozone, I personally feel we are in a position to make a rough assessment. I have attempted to do this, not as an economist but as a scientist; my economic colleague might like to be thought of as a scientist.

The assessment of crop loss from ozone has been accomplished using two different data sets. The first data set was one that was compiled in association with a National Academy of Sciences review that was completed in 1977. These data were then analyzed by EPA staff using a number of equalizing assumptions that tried to account for differences between injury and yield, because for this particular data base the response of concern was injury and not yield. There is concern is the scientific community with this data base because injury was the response parameter. Other assumptions considered the time of year when maximum exposure might occur, and the sensitivity of the plants themselves. The data show an estimated $990 million annual loss at the current ozone standard out of a $50.7 billion crop production year in 1977, which comes out to about a 1.95-percent crop loss. At the time, Lokey and his colleagues believed that this information was too tenuous to use in the standard-setting process.

The second analysis utilized a very small data base consisting of dose-response experiments performed under field conditions where the yield of the crop was measured and related to the average maximum 7-hour-per-day seasonal ozone concentration. These data were analyzed using regression analysis and yield reductions were calculated for different maximum 7-hour-per-day seasonal ozone averages. Work that has been done in terms of correlating the standard of 0.12 ppm for 1 hour with a maximum 7-hour-per-day seasonal mean concentration would suggest that the 0.12 ppm hourly standard would represent somewhere between a 0.06 and a 0.07 average seasonal ozone concentration. From these dose-response data, dollar losses were calculated using 1978 crop production figures along with the current air quality standard. These data suggest that yield losses could be as high as $3.02 billion to $4.18 billion at the current ozone standard. This would be about a 6.68-percent crop loss.

Now, it is my personal opinion, because of the general assumption made, that crops across the United States would not be in a uniformly sensitive state during much of the growing season. Thus, we need to reduce the above estimate by 50 percent. Even this would result in a 3.34-percent loss to crops. When this is done, the two assessments that were accomplished by two completely different techniques differ by only a factor of 1.7. It would seem a reasonable assumption that if all areas of the United States were just meeting the current ozone standard, the losses to crop production would be between $1 billion and $2 billion, or from 2 to 4 percent of total agricultural production.

This does not include forestry. It only includes agronomic and horticultural crops. In making this assessment, I am fully cognizant of the rough and incomplete data that went into both assessment approaches; also, the dollar value is not meant to show current losses in the United States but, rather, losses that would occur if the entire country just complied with the current standard.

Under crop loss assessment, the last paragraph touches on sulfur dioxide and nitrogen dioxide. In a simple summary on this, it is my belief that although there would be some injury and loss associated with sulfur dioxide itself, I believe it would be relatively small in comparison to the loss that we are suffering from ozone.

There is no reliable information on loss from nitrogen dioxide by itself. I feel, from data that is available, that the occurrence of sulfur dioxide and nitrogen dioxide in combination with ozone could contribute to up to 50 percent of the perceived crop losses associated with ozone.

We have done very little work on pollutant mixtures. There is a need to do much more in this area.

I have included a small section on strategies to alleviate pollution effects. The Environmental Protection Agency has used control of emissions as their primary strategy for alleviation of effects. Within the U.S. Department of Agriculture, I believe the best technique we can use is the development of breeding programs; Dr. Heggestad touched on this in his discussion this morning.

It is my personal opinion that we in agriculture will have to do something in terms of breeding programs or other protective techniques because I do not foresee a reduction in the levels of air pollution in this country in terms of citizen willingness to support more stringent controls. I expect ozone concentrations to either stay about where they are or, if anything, to increase with the present feelings of the country. So I think it is very important that we in agriculture do initiate some programs to try and develop more resistant cultures.

Generally, in terms of research need to assess crop losses, I think there is a need in the United States to develop a national program. Such a program has been initiated by EPA to look at an assessment of crop losses from ozone; actually from all three of these pollutants, but primarily from ozone. I think we currently have the techniques and several of the people who have presented testimony today have commented on these techniques.

The current field technique that is most widely accepted is the use of the open-top chamber. This is being used in the national crop loss assessment network [NCLAN] which is a cooperative effort by the EPA. It has national significance, and is currently in its second year of operation. It is programed for a 5- or 6-year time period and our expectation is that at the end of this period we will have a good economic assessment of losses to crops from air pollutants. These estimates will be much better than anything we have right now, and they will be based on sound field data.

There are some critical issues. Most of these Dr. Jacobson has addressed. They relate primarily to the monitoring data, the need to collect data in rural areas and to develop methods of analyzing this data in order to correlate it with crop losses. We need additional research on how to handle pollutant mixtures and then to understand the importance of pollutant mixtures under field situations.

I have included as attachments several articles that have discussed research needs. Because of that I have not dwelt specifically on research needs other than the general need to do fieldwork to assess effects.

[The prepared statment of Dr. Heck follows:]

STATEMENT OF DR. WALTER W. HECK

RESEARCH LEADER AND PLANT PHYSIOLOGIST
AIR QUALITY RESEARCH PROGRAM
AGRICULTURAL RESEARCH SERVICE
U.S. DEPARTMENT OF AGRICULTURE

BEFORE THE JOINT HEARINGS OF THE

SUBCOMMITTEE ON NATURAL RESEARCH, AGRICULTURAL RESEARCH,
AND ENVIRONMENT OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

AND THE

SUBCOMMITTEE ON DEPARTMENT OPERATIONS, RESEARCH,
AND FOREIGN AGRICULTURE OF THE

COMMITTEE ON AGRICULTURE
U.S. HOUSE OF REPRESENTATIVES

July 9, 1981

Mr. Chairman and Members of the Committee, I am Dr. Walter W. Heck, Research Leader, Air Quality Research Program, Agricultural Research Service, United States Department of Agriculture, North Carolina State University, Raleigh, North Carolina. I appreciate the opportunity to appear before you today to discuss the impact of air pollutants on agricultural productivity.

The effects of air pollutants on crops have been studied for many years. Over the past few years I have authored or co-authored a number of review articles that cover the relevant research. Several of these reviews are included as attachments (1, 2, 4, 5, 6, 7, 8, 9, 11) that might prove helpful to your understanding of the effects of air pollutants on crop production. Four publications directly address the assessment of crop losses (attachments 2, 3, 6, 7) as does the manuscript by Lokey et al. (attachment 10). Two of the attachments address research needs and approaches (4,9). The 1973 article (9) is still pertinent even though written over eight years ago. The second article (4) will soon be published and was given as a major address to the 32nd University of Nottingham School of Agricultural Science last September. This article (4) defines my current concepts in terms of research needs to understand the effects of air pollutants on crop production.

Sulfur dioxide (SO_2) from, the smelting of ores was one of the earliest pollutants identified as causing an effect on crop production. It was extensively studied during the first half of this century then received less emphasis until the recent construction of large megawatt, coal burning power plants. Ozone (O_3) formation is associated with automotive and industrial emissions that are changed in atmosphere by photochemical reactions to produce O_3. Crop loss to some components of this photochemical oxidant complex was first identified in the late 1940's. Ozone was identified as the primary active phytotoxic component in 1958. Nitrogen dioxide (NO_2) is released in all high temperature combustion processes. The NO_2 alone generally is not associated with plant injury at most ambient concentrations. However, it is an important ingredient of pollutant mixtures.

These three compounds (O_3, SO_2 and NO_2) are the most important phytotoxic air pollutants in the United States because of their phytotoxicity, ambient concentrations, frequency and duration of occurrence, and area of occurrence. Both O_3 and NO_2 are ubiquitous across the United States while SO_2 is becoming more so with the increased construction of electric generating plants that utilize coal. In my opinion, O_3 alone or in combination with SO_2 and NO_2 is responsible for up to 90 percent of the air pollution caused crop loss in the United States.

It is important to understand the air pollution system (Figure 1 in Reference 4) to know where crops fit into that system and thus the factors that must be considered in studying the crop component of that system. Knowledge of emission data is used to estimate local pollutant concentrations and an input to atmospheric chemistry models. Knowledge of meteorology and atmospheric chemistry are essential to understand atmospheric transport and transformations. Current information suggests that long-range transport is the primary cause of peak O_3 concentrations in rural areas of the United States that are east of the Rocky Mountains. Our understanding of long-range transport is fragmentary. It must be better understood if we are to adequately assess the national impact of air pollutants on crop production. The remaining elements in the air pollution system are economic, social and legal in nature. These elements accept data from the physical and biological elements to determine impacts on human values which are then used to assess needed air pollution control strategies.

Vegetation (crops) is the most sensitive biological component to air pollution stress from O_3, SO_2 and NO_2. It is critical to agricultural production that this fact be recognized and that any air quality standard include an assessment of crop losses. In respect to known effects, primary and secondary standards should be different. We should at least understand the economic impact, if we decide to adopt a single standard. The current O_3 standard of 0.12 ppm for one hour is not protective of crops but may be realistic when comparing costs of control with benefits of control.

Crop Loss Assessment

Assessment of crop loss from O_3 has been accomplished using two different sets of data. The first data set was a compilation of 1060 data points from 74 references that were critically screened for acceptability in dose-response calculation. Summaries of these data, analyzed using the Larsen-Heck model, are found in Table 3 (specific species and cultivars) and Table 4 (combinations of species and cultivars) of attachment 7. Data for percent injury to the plants after exposure for 8 hours to 0.10 ppm of O_3 (which is associated with the current one hour standard of 0.12 ppm - attachment 10) show values of 21, 2 and 0% average injury for the all sensitive, all intermediate and all resistant plant categories respectively. This data was analyzed by Loken et al. (attachment 10) using a number of equalizing assumptions that tried to account for differences between injury and yield, time of year when maximum exposures might occur, and sensitivity of plants. Their data show an estimated $990 million annual loss at the current O_3 standard out of a $50.7 billion crop production year (1977) or a 1.95% crop loss. Lokey et al. believed this information was too tenuous to use in the standard setting process.

The current O_3 analysis utilized a much smaller data set from dose-response experiments performed under field conditions. The desired yield of the crop was measured and related to the average maximum seasonal 7 hr/day O_3 concentration. The current standard of 0.12 ppm for one hour would give between an 0.06 and 0.07 ppm average seasonal maximum 7 hr/day O_3 concentration over a 2 to 3 month growing season. These data were analyzed by Heagle and Heck (attachment 2) using regression analysis and yield reductions at different average seasonal maximum 7 hr/day O_3 concentrations were calculated. From these yield reductions dollar losses were calculated using 1978 crop production figures ($53.92 billion). These data suggest that yield losses could be as high as $3.02 to $4.18 billion at the current standard (average of 6.68% crop loss). This analysis would assume that crops in all parts of the United States are in a sensitive state during must of the growing season. [illegible]s assumption is weak and the values should probably be reduced by 50% (3.34% crop loss). When this is done the two rough assessments, accomplished by two completely different techniques, differ by a factor of 1.7. It seems reasonable to assume that, if all areas of the United States were just meeting the current standard (0.12 ppm for one hour), the losses to crop production would be between $1 and $2 billion or from 2 to 4% of total production.

In making this assessment, I am fully cognizant of the rough and incomplete data that went into both assessment approaches. Also, the dollar value is not meant to show current losses in the United States but rather losses that would occur if the entire country just complied with the current standard. Most sections of the country are above the standard and thus current national losses are probably higher than these estimates even when major regional environmental differences are taken into account.

Crop losses from SO_2 have usually been associated with acute episodes from SO_2 releases from smelters or power plants. The importance of the higher concentration episodic SO_2 events were of primary importance in the setting of the current SO_2 secondary air quality standard. These episodic events are occurring less frequently in the United States, with the advent of high stacks, and we are becoming more aware of the potential for chronic SO_2 effects. This is especially true in highly industrialized areas where multiple sources may keep the SO_2 concentration at or above a threshold concentration for sensitive crops. These is increasing concern with the widespread occurrence of chronic SO_2 exposures in conjunction with low concentrations of NO_2. Both of these gases may occur in conjunction with both chronic and acute exposures from O_3. There is no evidence that NO_2 alone, at current ambient concentrations, has an impact on crop production. There is evidence of an effect from SO_2 alone but no reasonable estimates of crop losses are possible - projected losses as high as $20 million per year seem high. Thus, the importance of SO_2 and NO_2 lie in their potential for adding to or increasing the losses caused by O_3 alone. There are no reliable data for the size of these losses but they could contribute as much as 50% to the perceived crop losses associated with O_3. Neither air quality data nor effects research are at a stage to permit an estimate of the importance of various combinations of those three pollutants.

Strategies to Alleviating Pollution Effects

The Environmental Protection Agency uses control of emissions at the source as its basic strategy to alleviate effects. I believe alternative strategies are needed within the agricultural community because I expect the air pollution levels to stay fairly constant or even increase in the foreseeable future. This analysis is based on several facts: the small effects over large areas tend to hide the overall importance of air pollution effects on crops, and thus lessen concern for crop losses, and a concern for over-regulation, and a move toward cost/benefit approaches in control strategies may result in a relaxation of standards.

Agricultural strategies considered to date include: recommendations for changes in cultural practices (i.e., irrigation control), use of protective sprays, recommendations for the use of cultivars and species in different parts of the country depending upon the pollution severity, and the development of resistant cultivars within species. The last strategy, to incorporate air pollution stress into breeding programs, is the one best accepted by plant scientists. There is ample evidence that it will succeed, if current pollution levels do not significantly increase.

Research Needs

It is essential that we develop meaningful estimates for crop losses that can be related to air pollution dosages over growing seasons. This information is critical for the development of standards and for cost/benefit analyses used in air pollution control strategies. Within the United States Department of Agriculture, these assessments are needed so we can more accurately determine the resources that should be allocated for the development of more resistant cultivars and to find practical ways to protect crops from air pollutants.

Assessment of crop loss associated with environmental stresses is not easily determined. Even today we have no universally accepted methodology, although an epidemiological approach is being used for biotic pathogens. For acute episodic air pollution events, this approach is probably valid. However, over the growing season, there are vast areas of the country where the differences in the average concentration of each of the 3 gases, during peak daylight periods, are not very different. Additionally, the gas concentrations vary around the threshold of effects for many of the more sensitive crop species. These two factors suggest that for a national assessment the epidemiological approach is not feasible.

A number of field techniques have been tried. The open-top chamber approach has been accepted by research workers within the air pollution field as the best available technique. The technique permits experimental control of the air mass around the test plants with a minimal change in the field amounts of O_3 to the ambient level for a given number of hours per day. This design was used to develop the dose-response functions by Heagle and Heck (attachment 2). The open-top chambers can also be used for other gaseous pollutants such as SO_2 and NO_2, although the method of pollutant addition would be changed in areas where little SO_2 or NO_2 is present in ambient air. The experimental technique design can be used with gas mixtures.

The open-top chamber approach was the approach chosen by a major Environmental Protection Agency cooperative program (the National Crop Loss Assessment Network - NCLAN). This program was set up to develop an indepth assessment of the effects of

O_3, SO_2 and NO_2 on crop production. The NCLAN program has a major modeling and economic component. Crop loss as a function of pollutant concentration will be the primary ingredient of the crop loss model. The NCLAN program will gather data from a number of regional experimental sites using a number of plant species and cultivars. Environmental parameters that are known or suspected to affect plant response to the pollutants will be monitored. These data will be used over several years to develop a crop loss-pollutant dose assessment model that will determine annual economic losses to crops due to pollutant stress. This is the first comprehensive program developed to assess crop loss from pollutant stress. The overall goal of NCLAN is to understand the effects of the air pollutants O_3, SO_2 and NO_2 on crops and to determine the economic losses associated with these pollutants.

I have made a comprehensive listing of more detailed research needs in two publications (reference 4, Table 3 and reference 9). For crop species, these research needs are included in the NCLAN program objectives. Currently only the primary NCLAN objectives are being funded.

Critical Issues

In addition to the above research needs, there are several critical issues that must be addressed by air pollution scientists before a reasonably accurate national assessment of economic losses to crops from air pollutants can be determined. These issues include the:

(1) Collection of additional monitoring data in rural areas for the three major pollutants.

(2) Detailed analysis of air quality data to develop the best averaging technique for significent correlations with crop yield.

(3) Development of methodology for handling and interpreting data for studies of pollutant mixtures. This should include an analysis of air quality to determine various ratios of the three gases in ambient air.

(4) Development of methods for understanding the relationships between air pollution stress and other stress factors on crop yields.

Mr. Chairman, this completes my prepared statement. I will be pleased to respond to any questions you may have.

List of Attachments

1. Environmental Protection Agency. 1973. "Effects of Sulfur Oxides in the Atmosphere on Vegetation." 43 pp. EPA-R3-73-030. Research Triangle Park, N. C.
2. Heagle, A. S., and W. W. Heck. 1980. Field methods to assess crop losses due to oxidant air pollutants. In: Proc. of E. C. Stakman Commemorative Symposium "Assessment of Losses Which Constrain Production and Crop Improvement in Agriculture and Forestry." pp. 296-305. Misc. Publ. 7 - 1980. Agric. Expt. Stat., Univ. of Minn., St. Paul, Minn.
3. Heagle, A. S., A. J. Riordan, and W. W. Heck. 1979. Field methods to assess the impact of air pollutants on crop yields. Presented at the 72nd Annual Meeting of the Air Pollution Control Association. Cincinnati, Ohio. June 24-29, 1979. 26 pp. No. 79-46.6.
4. Heck, W. W. Future directions in air pollution research. 1981. In: Proc. of the 32nd University of Nottingham School in Agricultural Science: Effects of Air Pollution on Agriculture and Horticulture. University of Nottingham, Nottingham, England (In Press) (Review)
5. Heck, W. W., and C. S. Brandt. 1977. Effects on vegetation: native, crops, forests. In: "Air Pollution" (A. C. Stern, ed.). 3rd edition, Vol. 2, pp. 157-229. Academic Press, New York, N. Y. (Review)
6. Heck, W. W., A. S. Heagle, and E. B. Cowling. 1978. Air Pollution: Impact on Plants. Proc. Soil Cons. Soc. Am., August 7-10, 1977. Publication No. 32:193-202. (Review)
7. Heck, W. W., R. I. Larsen, and A. S. Heagle. 1980. Measuring the acute dose-response of plants to ozone. In: Proc. of E. C. Stakman Commemorative Symposium "Assessment of Losses Which Constrain Production and Crop Improvement in Agriculture and Forestry." pp. 32-49. Misc. Publ. 7 - 1980. Agric. Expt. Stat., Univ. of Minn., St. Paul, Minn.

8. Heck, W. W., J. B. Mudd, and P. R. Miller. 1977. Plants and microorganisms. In: "Ozone and Other Photochemical Oxidants." pp. 437-585. National Acad. Sci., Washington, D. C. (Review)

9. Heck, W. W., O. C. Taylor, and H. E. Heggestad. 1973. Air pollution research needs: herbaceous and ornamental plants and agriculturally generated pollutants. J. Air Pollut. Cont. Assoc. 23:257-266. (Review)

10. Lokey, Don, Harvey Richmond, and Michael Jones. 1979. Revision of a Secondary National Ambient Air Quality Standard-Ozone: A Case Study. Preprint 79-46.1. 72nd Ann. Meeting Air Pollution Control Assoc. June 22-27, 1979. 34 pp. Air Pollution Cont. Assoc. Pittsburgh, Pa.

11. Reinert, R. A., H. E. Heggestad, and W. W. Heck. 1981. Response and genetic modification of plants for tolerance to air pollutants. In: "Breeding Plants for Marginal Environment" (Christiansen & Lewis, eds.). pp. 381 458. J. Wiley & Sons, New York, N. Y. (In Press)

Mr. BROWN. Thank you very much, Dr. Heck. Mr. Scheuer?

Mr. SCHEUER. Thank you, Mr. Chairman, and thank you, Dr. Heck, for your very interesting testimony.

You talk about crop losses between $1 billion and $2 billion, which sounds like a lot of money and looks like a lot of money. These losses would be only 2 to 4 percent of total production. I would think a loss in any creative process, whether it is manufacturing or crops or student dropouts or anything else, a loss of 2 to 4 percent in your total production would be looked upon as a manageable loss.

Further on in your testimony you talk in detail about a crop breeding program. Are you trying to tell us that the costs of reducing the losses below this 2 to 4 percent, below this $1 billion to $2 billion level, would be so high if we have to do it through cleaning up all of our environment that we could achieve a reduction of this $1 billion to $2 billion loss more effectively, more cost effectively and more sensibly through the breeding approach that you discussed—the crop breeding approach?

In other words, should that be the target of opportunity?

Dr. HECK. This isn't a decision, of course, that I would need to make. We know enough about resistance within species that we could develop breeding programs that would permit us to make use of the more resistant gene pool——

Mr. SCHEUER. Excuse me. I didn't hear that. Maybe you could pull the mike a little bit closer.

Dr. HECK. We do have enough information on resistance within species that we could develop varieties and cultivars that are much more resistant to ozone. I think, therefore, we could reduce our crop losses by breeding programs.

As far as I know, we have no major breeding program that has included air pollution as a primary stress. We have inadvertently included air pollution for a variety of reasons that Dr. Heggestad mentioned in his testimony. I think it would be cheaper to do this than it would be to control air pollution at the source. But whether the United States as a nation wants to take that approach of maintaining dirty air and trying to protect its crops by breeding rather than cleaning up the air is something that other people would have to make a decision on.

Mr. SCHEUER. I suppose you would also have to factor in, if you decide to live with the dirty air the devastating effects on buildings, materials, and also on human health.

Dr. HECK. That is right.

Mr. SCHEUER. Now, there are those—in fact, there was an Op-Ed piece in the Washington Post about a week or 10 days ago—who say that really before you spend hundreds of billions of dollars cleaning up the air, we ought to spend an infinitesimal fraction of what that cost would be making sure that the air in our homes, in our buildings, is comparatively clean and pure and benign, because that is where we spend 90 to 95 percent of our time. The article went on to discuss formaldehyde and one or two other chemicals that are toxic that are found in homes.

From the cost/benefit point of view, we should certainly address the indoor air problem first and achieve far safer levels of air pollutants as far as human health is concerned at a minimum cost. In effect, you are saying more or less the same thing for crops, try and mitigate at a comparatively minor expense the cost of crop loss by plant breeding, since your loss is only 2 to 4 percent of the total crop yield anyway.

I think that is not an approach that the environment purist and consumer groups are going to applaud us on. A lot of people would look upon that as a depressing approach, but in times of financial stringency it may be that we certainly should be looking at this type of an approach for crop loss, building loss, and human health. We should strive for short-term solutions in all three areas while we make plans to really get a handle on the total problem and the source problem in the long term, which is going to require the expenditure of tens if not hundreds of billions of dollars.

I don't want to put words in your mouth, but it seems to me you are saying that while you go ahead with the long-term plans, at least make short-term plans to mitigate the loss at a far lower level of expenditure.

Dr. HECK. I personally feel we need clean air and I am a proponent of the best available technology for cleaning up the air. I think it is important that we do this. I don't think it is always done. I am also a realist, and I feel I have been for a number of years. The realism I have is that the people in the United States are not willing to spend the money to put in the control devices to clean up the oxidant air pollution, the ozone air pollution, and because of that we are going to have to find some way in agriculture to reduce the losses if we possibly can.

The only way I can see to do this is by breeding programs. We have had an ozone standard, as an example, in the United States for probably 10 years. It was originally 0.08 ppm. I don't know of any place in the Eastern United States that ever met that standard, and no city of any size in the Western United States ever met that standard. That is one of the reasons I raised no strong objections in discussions with EPA when they revised the standard to 0.12 ppm. As a matter of fact, in the work we have been doing at Raleigh, N.C., which supposedly is one of the cleaner States in the East, and it is a beautiful State, we have never in the 8 or 10 years we have been doing research there seen a summer that didn't go over the current standard, the 0.12 ppm.

So my practical reasoning tells me we will not meet that standard. It is important that we know what the air pollution levels are in this country and what the crop losses are; you must remember that the estimates I gave you were estimates based on meeting the standard. I don't know what the corp loss estimates really are in the Unites States, since the standards are not met anywhere in the East, but the losses are surely higher than what I've indicated.

Mr. SCHEUER. Well, your testimony has been extremely interesting. In deference to your patience and everybody's time, I am going to defer further questions, Mr. Chairman, and I would like to ask unanimous consent for us to address some further questions to the witness in writing.

I just have one last question. Would you like to be the person designated by the Secretary of State to tell the Canadians and the Scandinavians that they ought to develop more resistant crops and that they are going to have to live with this problem for some period of time and they better get about the business of developing crops that will stand up to all of that pollution that crosses the border? The Scandinavians should learn to live with what is coming as a gift from their southern neighbors in England, France, Germany, and Belgium, and the Canadians better start to think about accepting graciously those pollutants and develop crops that will stand up and flourish under that barrage.

Mr. BROWN. That is a rhetorical question, Dr. Heck.

Dr. HECK. I felt it probably was.

Mr. BROWN. You can just say no and it will be all right.

Mr. Roberts, do you have any questions?

Mr. ROBERTS. Yes, Mr. Chairman. Thank you.

I want to echo the sentiments of my colleague, who I think made a very fine point that it was not too long ago that our subcommittee, under the persistent and effective leadership of our chairman, was investigating this same area in terms of moisture research and we have those in my country who would like to build a water transfer device, which I call a big ditch and they call a canal, from the Missouri River out to the High Plains.

It was my point at those hearings that you could save a great deal of money, instead of spending billions for that project, in terms of the same kind of research on moisture stress. I guess my question to you, and it is a lay question and I apologize for not having the information, but where are we in terms of research in your estimation? How many years down the road will it take before these kinds of plants will be commercially available to the producer? I am talking about a strain of wheat that would be more resistant to pollution.

Dr. HECK. In areas where there has been no attempt to start a breeding program, we could be 5 or 10 years down the line from that. One of the things that we all need to be aware of, of course, is that when we deal with forests it is not that easy, and when we deal with natural systems it is an impossibility.

The only place that breeding will help, I think, would be with crops, primarily annual crops. Now, in some species—tobacco is a good example of this since I come from a tobacco State—we already have fairly tolerant cultivars that have been developed because of selection on the part of the farmers. When they see very sensitive plants in the field, they tend to put them aside and make use of plants that are more resistant for their seed sources.

So a little selection has already been done.

Mr. ROBERTS. I wasn't even aware that the national crop loss assessment network existed. I don't think too many of my producers are aware of it, either, and I would hope that this kind of effort could be better publicized or, I don't know, perhaps the onus is on people like myself.

You indicated that you are about 5 or 6 years down the road from now in terms of your assessment as to where you want to be with this program?

Dr. HECK. Correct. Our date on this is 1985. We expect to have good information each year. Last year was our first year, and we are just finishing up our first annual report. We are in the process of our second year right now, and in a couple of years we should have the first economic assessment, using the models that will have been developed from this work. We are looking now at 1985 as the time when we will complete the first phase, and we should have several very good empirical models.

The long-term approach is to develop more mechanistic models so we understand what is happening. We feel that probably is about 10 years down the way.

Mr. ROBERTS. I would like to have a copy of that first-year assessment. I would hope that members of both subcommittees could have a copy of your second-year assessment, and I would like to make it available to the farm press in my district all over the area. I think it is a very valuable thing and I just don't think too many farmers are aware of it. I know the Wildcats are at K State and the Wolf Pack is at North Carolina, but I am not too sure about how many people understand.

I have no further questions.

Mr. BROWN. Thank you very much, Mr. Roberts.

Dr. Heck, I have a limited familiarity with efforts to breed crops to withstand certain kinds of stress. For example, we have a salinity laboratory in my area which has been breeding salt-resistant crops and I presume that the history of the Department of Agriculture has included a great deal of work over the years in breeding crops to resist stresses from certain factors such as insects, viruses, all that sort of thing.

But your testimony is that we have done relatively little in terms of breeding for air pollution.

Dr. HECK. Correct.

Mr. BROWN. But based on the success in other stress areas, your estimate of a 5- to 10-year period you think is reasonable to show some progress in this field?

Dr. HECK. Yes, I do.

Mr. BROWN. I have no further questions, Dr. Heck. Thank you very much for your testimony.

Dr. HECK. Thank you, Mr. Chairman.

Mr. BROWN. Our last witness this morning is Dr. Walter Page from West Virginia University. We are pleased to have Dr. Page here this morning.

STATEMENT OF WALTER P. PAGE, PH. D., WEST VIRGINIA UNIVERSITY

Dr. PAGE. Thank you. My training is as an economist.

Mr. BROWN. For the record, let us state that economists can be scientists also.

Dr. PAGE. Thank you. My area of specialization is energy and environmental research, and the purpose of my testimony this morning is to give you information on a recently completed project which was congressionally mandated and carried out under the auspices of the U.S. Environmental Protection Agency.

The project was the Ohio River Basin energy study.

Does everybody have a copy of the written testimony?

Mr. BROWN. Yes, and the full text will be included in the record, Dr. Page.

Dr. PAGE. All right. The reason I ask is that I brought transparencies of the figures, but if you all have copies, it is perhaps easier to just look at the copies.

Exhibit 1 shows the boundary area for phase II of the study. It included all of Kentucky, most of Illinois, Indiana, Ohio, Pennsylvania, and West Virginia. The object was to assess the environmental, health, and related impacts of proposed utility developments in the Ohio Basin area. Utilities were proposing large increases over time in regional megawattage, particularly the lower portion of the Ohio River Basin.

Several concerned citizen groups applied pressure to get this particular study mandated. The study was an integrated technology assessment where a series of models were used to derive sets of conditions that might be experienced in the region in order to assess the relative economic, environmental, et cetera impacts.

Exhibit 2 shows the sequence of information flow lending to the economic assessment of regional agricultural damages. In part, I give this to you as a copout so that I will not be held responsible for the work done by biologists and engineers, but the sequence of events leading to my work was as follows:

There was developed an energy and fuel demand model by myself and others which served the purpose of projecting the economic characteristics in the ORBES region out to 2000. That information, in turn, was used by Teknekron Research, Inc., for purposes of calculating emissions and concentrations in the region to 2000. That information, in turn, was given to Dr. Orie Loucks of the Institute of Ecology [TIE], and he used that information to calculate for SO_2 and SO_3 concentrations, the associated physical crop losses. I used that information, in turn, for purposes of monitorizing those losses in a way consistent with economic principles.

I can add nothing to these hearings in terms of physical dose-response curves, and a set of numbers provided by TIE which consisted of losses in the base period, 1976, and estimated losses for 1985 and 2000.

If you look at the information that we had available, what seems to happen is the emissions and concentrations were roughly linear over the 1976–85 and 1985–2000 periods. The dose response functions used by Orie Loucks are characterized as having fixed coefficients. As a consequence, it was possible to estimate damages for years in each subperiod by linear interpolation.

So in that way we were able to estimate what the anticipated damages would be for every year, 1976 to 2000, and for the methodology I was using it was necessary that I have those annual estimates.

I assume a broad purpose of this hearing is also that of gathering information in connection with revisions to the Clean Air Act or its continuation. As that is the case, I think what I will do in the testimony is to try to stress the implications of this work for certain policy aspects related to the Clean Air Act.

I understand, for instance, that there is serious discussion of revisions which modify or do away with secondary standards, which is, of course, what we are talking about here. Because this is the case, I am going to stress the policy implications of our results.

Because of the unique charge given to the ORBES project, we were interested in estimating damages in the aggregate as well as those which we thought could be uniquely attributed to utilities. This was necessary in order that we satisfy the congressional mandate for the study. So my results will also include that discussion of the utility-related losses as well as total losses.

I have to describe for you the three cases that I will be discussing.

One is a so-called scenario 2 which was our best guess of what really might happen in the region between 1976 and 2000. With respect to air, the scenario assumed that all SIP's, State implementation plans, in those six States were fully complied with. It also assumed new source performance standards and revised new source performance standards were all complied with. That kind of a scenario we thought of as a business-as-usual sort of scenario.

The second scenario that I will be discussing is scenario 2d. That scenario was identical in all respects to the one that I have just described except SIP's are not complied with, so it is a "dirty-air" scenario. The object of investigating the implications of that were for purposes of contrasting it with the previous case. In fact, it may be a more realistic case when you look at Ohio, in any event.

Scenario 7 is what we thought of as a high-growth scenario in the region. It was put together by assuming a higher growth rate of the regional economy and a higher growth rate in the regional demand for electricity.

So I will report to you results and contrast results as between those three cases. I should make a general observation, in light of some of the comments and questions that I have heard this morning, that to an economist, when you think about air pollution and the damages which accrue, you are talking about what we term a production externality. The characteristic of it is that somebody is doing something, producing residuals, whether they be gaseous, liquid or solid, that has an adverse effect on someone else, and that is just a simple notion of a production externality.

The problem historically has been that it was, for all practical purposes, not possible for the recipient of damages to reduce emissions from someone else. And, of course, the long-range transport phenomenon just highlights that. It is probably quite clear now that ambient air in the Adirondacks is best explained by the level of emissions from utility and other point sources in the Lower Ohio Basin. There is no way people living in the Adirondacks in the past have been able to recover the cost of those damages.

Now, the 1977 amendments did, of course, include a provision which somewhat changed that situation. The amendments permit a political jurisdiction to bring suit against another for using up its air quota, so to speak. There are cases in the courts now. There is a mechanism that is beginning to be developed which permits, then, the recipient of damages to try to reduce harmful effects which are generated by other producers geographically dispersed.

So I think it is important that we recognize that this kind of provision does exist and there are some possibilities that it may be expanded, particularly when one thinks of the bubble concept which is currently being discussed within EPA and when one thinks of things like "pollution rights" which, through the sale of pollution rights, would provide a mechanism for establishing an optimal level of pollution.

The results that I will discuss this morning are related only to direct losses suffered by agricultural producers. They do not include a wide array of indirect losses which also are experienced. To illustrate the point, if there is a reduction in productivity and output in a specified region, then there is also a reduction in the dollar value of activity in the transport sector that moves agricultural goods, perhaps in the fertilizer sector that sells fertilizer, et cetera, so there are other indirect losses. My loss estimates, being only the direct losses, then, are an understatement of the true magnitude of losses. I have a graduate student completing work, following up on this, where he is estimating indirect losses.

This work reported today, we are estimating monetary losses over a 24-year period, so it was necessary to make some assumptions about what the agricultural sector and agricultural prices would be doing over a 24-year period. As what we are up to here is really comparing results as between cases, it was really only important that we have a consistent set of assumptions that we used in all of the cases. So what I decided to do was to confess my ignorance and say I don't know whether the agricultural sector acreage is going to get larger or smaller in this region over time. I doubt it would get bigger. It might get smaller.

So I assume the size of the agricultural sector is unchanged over that 24-year period and I assume that the real price of agricultural goods was constant, which is to say that the price of agricultural goods would be increasing at the same rate as inflation.

I think we can turn to exhibits 4, 5, and 6, then, which show you the kind of results that we obtained. The total research report is very large and I did not bring it with me. The report contains many calculations that are not represented in these 4 exhibits. In particular, it is important to note that in doing the research we examined really 3 cases within each scenario. We examined the Institute of Ecology's best guess as to minimum losses, maximum losses, and probable losses. What is reported here are my calculations of economic damages which are associated with the probable case of crop damage.

I have had long discussions with Orie Loucks and others on this matter. In the community of biologists and others there seems to be some disagreement as to whether you should think in terms of a range, a minimum to max, or whether one feels comfortable establishing something called probable. I think—I can, of course, not speak for Orie Loucks—but I think when he calls these probable, he means just that; they are likely to occur. So this is what I will be reporting.

First of all, I do not provide you with annual estimates. I provide you with the present discounted value of cumulative losses, so the numbers are big because they represent the losses that occur over a 24-year period. The reason I do this is because what I am really interested in here is trying to get a sensible way to translate these numbers so that people can understand what they mean, and the way I have chosen to do it is to estimate what that cumulative damage value would be from agricultural production over the 24 years compared with the value if the air were clean; that is, if you did not suffer damage from airborne residuals.

By doing this, I am able to compare the losses in agriculture over the 24-year period from the hypothesized ambient air quality with the dollar value of output if the air were clean for each of their cases.

In exhibit 4 I break out those cumulative losses by State. I calculate the percent the State losses are of total regional losses. The reason to do this is it is not only important to understand that within this region there are significant losses; it is important to understand how they are distributed in the region.

I suppose the first point of interest is the fact that for the region as a whole these calculations suggest that cumulative losses are on the order of 10 percent of the value of pollution-free output. That is not to say that in a given year they would be 10 percent, because if you look at the emissions and concentrations information over time, it increases out to 1985 and then SO_2 tends to decrease after 1985 but NO_x emissions keep increasing; hence, ozone concentrations keep rising. So you cannot say that in a given year that is the loss. What you can say is that over the 24 years the dollar value of losses would be on the order of 10.3 percent of the dollar value of clean air production for the same period.

Mr. SCHEUER. In dollar terms, does that mean $7 billion to $3 billion?

Dr. PAGE. Yes, sir.

Mr. SCHEUER. Under that, in the parentheses, what is that?

Dr. PAGE. All of the numbers in parentheses refer to those losses uniquely attributable to utilities, so total losses would be 10.3 percent of the dollar value of clean air production. Losses uniquely attributable to utility activity would be 4.3 percent of the value of the clean air production.

Now, if you look at the third column of exhibit 4, this gives you the distribution of those losses by State. You will note that the losses are very highly concentrated in Illinois. By the way, the losses are calculated for corn, soybeans, and wheat, which I forgot to mention. They are highly concentrated in Illinois, Indiana, and Ohio.

A third point to be made from exhibit 4, which does not show up here but I will note it, is that within the three crops, the heaviest concentration of dollar losses is corn and the second greatest is soybeans. There was very little to wheat in part because there is very little wheat grown in that region. It is not a reflection, really, of anything physical; it is just a characteristic of the kind of agriculture in the region.

The extent of SO_2 losses within the region is very small, seven-tenths of a percent. The monetary losses attributable to ozone are 99.3 percent of the total losses, which I gather is consistent with what I have been hearing from previous testimony on physical damage to crops.

If you look at exhibit 5, that reports the same information but for the lax air case, the dirty-air case where SIP's are not complied with. The interesting thing to observe is that the numbers are almost identical. It did not matter to agricultural damages whether the SIP's were complied with or not. The reason—and this is where I wish to talk for a minute about policy—is that SIP compliance doesn't mean anything in this region with respect to NO_x emissions. Only Illinois has a SIP requirement on utility emissions of NO_x. So when you talk about SIP compliance in these six States, all you are really talking about is compliance with SO_2, but SO_2 doesn't matter in terms of the agricultural damages.

It seems to me that if one believes these kinds of numbers it is appropriate to consider further revisions of SIP's with respect to NO_x standards. A second and related point is that it is also appropriate to consider more stringent NO_x emission standards for NSPS and RNSPS plants because those emission limitations are very low.

If you look at the kinds of curves we generated on emissions, you observe that in almost all cases SO_2 increased to 1985 and decreased thereafter. The reason was that the assumed plant life for a utility meant that you were phasing out, through 1985, an increasingly large number of SIP plants and generating capacity was being satisfied by new source performance or revised new source performance plants which had stringent emission requirements on SO_2. So the curve of SO_2 emissions declines after 1985. But the NO_x standards are so low that in virtually every case we looked at NO_x emissions continued to increase all the way through the period.

So I think it is an important point to realize that the agricultural damages, at least, are very much related to the NO_x emission question and that is a question that has not in the past been seriously considered in promulgating standards for the Clean Air Act, and certainly it was not seriously considered when SIP's were set up or a revised SIP process gone through.

Finally, exhibit 6 contains again the same information. The only point I would make is that if you examine exhibit 6 and compare it with exhibit 4, the difference between the two cases is that in scenario 7 the assumed growth rate in the region was higher and we assumed a 45-year utility plant life rather than a 35-year which, by the way, turns out to be a very critical assumption in most of this stuff. If you change the assumed plant life by 10 years, all sorts of significant things begin to happen to emissions and concentrations and, indeed, there is reason to think that one response of the utility sector to existing regulations may well be to increase plant life over and above the historic average.

But in any event, from exhibit 6 you find that with the higher growth rate and the longer assumed plant life that the percent losses are of pollution-free output does rise to 12.3 percent. The distribution of those losses by crop, by State, and as between the two pollutants is virtually unchanged.

To sort of summarize, then, those materials, I guess it could be said that one would expect losses in this region to the agricultural sector to be on the order of 10 to 12 percent of the present value of clean air production in the region over the 24-hour period. One would expect the utility-related losses to be on the order of 4.7 or 4.8 percent of the value of clean air production. Losses are highly concentrated in Illinois, Indiana, and Ohio. Almost all losses are attributable to 03 and an assumed longer plant life and higher growth rate in the region does imply a larger loss but nothing terribly significant in a comparative sense.

I think I would like to make a few suggestions concerning research. You should realize that it is only in the very recent past that economists have turned their attention to estimating these things, these kinds of losses. You can number on the fingers of one hand, I suppose, the significant pieces of research that have been done by economists for this purpose. There are many evaluations out there which in terms of economic principles are not worth a great deal. You cannot multiply price by quantity to calculate the loss. That ain't the way you do it.

So when you think of estimates of these kinds of losses that are legitimate estimates, you are not thinking of very many pieces of work.

I suppose the primary suggestion that I would make, is to recognize the obvious fact that agricultural damages, whether they are being investigated to calculate monetary losses or physical losses, need to be based on regional characteristics; hence, the research almost certainly will have to consist of a series of regional studies.

I think that that work should be carried out on a large-scale basis by one group of individuals so that you don't have this problem of different methodologies, different data bases, et cetera. What I am suggesting, then, is if one really wants to get a handle on the extent of these losses nationwide, it should be a fairly large-scale research project conducted by one group where the framework of it is at the regional level.

It seems to me that this type of work almost has to be done by estimating both direct and indirect losses. I think if you are going to get any reasonable handle on the extent of losses, both have to be included. Probably the most appropriate framework for indirect losses is the use of some input/output tables, which is what my graduate student is doing at the moment.

I think that this kind of work should also pay particular attention to the possibility of estimating the control costs. There is much discussion these days of benefit/cost analysis. I welcome it because it tends to mean more employment for economists, I suppose, but if we are serious about benefit/cost analysis and if we are serious about promulgating standards related to ambient air, then it is necessary that we have a good handle on control costs, some good modeling vis-a-vis control costs, and modeling those technologies which are appropriate for reductions in emissions of those pollutants we are concerned with. So there really has to be some coordination between the engineers, geophysicists, economists, and those that do that sort of thing, as well as the biologists and economists that are looking at the agricultural damages.

Finally, if again we think of benefit/cost analysis, the benefits, of course, are improved health, greater longevity, improved productivity in agriculture, et cetera. The costs, of course, are the costs accruing from control technologies. It would be inappropriate to calculate a benefit/cost ratio where the benefits relate only to agricultural improvements. You would never get a value of 1. The benefit/costs have to be calculated over all benefits which accrue from improvements in ambient air, which suggests a very serious problem of getting together all of these kinds of people that look at health damages, agricultural damages, et cetera, to agree on a consistent way to evaluate the damages that they are interested in.

I think that probably completes my testimony.

[The prepared statement of Dr. Page follows:]

TESTIMONY OF WALTER P. PAGE, PH.D.

CONCERNING

AGRICULTURAL MONETARY LOSSES FROM AIRBORNE RESIDUALS

delivered before a joint hearing of the

(1) Subcommittee on Natural Resources,
Agriculture Research and Environment
of the Science and Technology Committee
(Chairman, James H. Scheuer)

and

(2) Subcommittee on Department Operations,
Research, and Foreign Agriculture of
the Agriculture Committee
(Chairman, George E. Brown, Jr.)

July 9, 1981

SECTION I: INTRODUCTION

This testimony is being provided on invitation from Representatives Scheuer and Brown, Chairmen, respectively, of the Subcommittee on Natural Resources, Agriculture Research and Environment and Subcommittee on Operations, Research, and Foreign Agriculture. The purpose of the testimony is to provide information on research recently completed under the auspices of the U.S. Environmental Protection Agency (EPA). The Project Officer for the research was Lowell Smith and the research results focus on the estimation of monetary losses to agricultural producers in the Ohio River Basin Energy Study (ORBES) region from airborne residuals. Research was supported under US-EPA Grant #805585 and Subcontract #805588. In addition to reporting the results of that research effort, the letter of invitation suggests that it would be appropriate to comment on research needs related to agricultural productivity as well as state-of-the-art models related to such activities. I wish to acknowledge the assistance of three individuals who participated in this research: Robert G. Fabian, James Ciecka, and Gary Arbogast. Fabian is an economist (Ph.D.) working as a private consultant in Chicago, Illinois; James Ciecka is an economist (Ph.D) on the faculty at DePaul University; and Gary Arbogast is a Ph.D. candidate in the Department of Economics, West Virginia University.

SECTION II: GENERAL BACKGROUND

The Clean Air Act is currently undergoing review with an eye toward possible modification. It is important that recent research results be available to Congress in order that informed decisions may be made concerning revisions of the Clean Air Act. As I understand this hearing, we are interested in the examination of research results related to the secondary standard provisions of the Act. Most research in the last two decades was directed toward primary standards (the preservation of human health). It is only in the last few years that significant research has been conducted which provides information on economic losses falling under the provisions of secondary standards. Research conducted on damages related to secondary standards suggests the need for reevaluation concerning the definition and permissible emission levels for criterion pollutants. Work also suggests the need to carefully examine revised State Implementation Plans (SIPs) as well as New Source Performance Standards (NSPS), Revised New Source Performance Standards (RNSPS), and Best Available Control Technology (BACT). The problem of harmful effects, both for primary and secondary standards impacts, is obviously much more complicated and far-reaching than was envisioned in the initial Act. Results will be presented in later sections of this testimony supporting that statement.

The complete results of the ORBES project may be found in the EPA document #600/7-81-008 (January 1981) entitled Ohio River Basin Energy Study (ORBES): Main Report [1]. For purposes of this testimony, it is only necessary to describe the geographic region encompassed by the ORBES project and the information flow between various research components which culminated in the estimation of monetarized losses to agricultural producers in the region.

Exhibit 1 shows the physical boundaries of the study area for the ORBES project. Figure 1-1 in Exhibit 1 shows the boundary area includes all of Kentucky and portions of Illinois, Indiana, Pennsylvania, West Virginia and Ohio. State areas were excluded which would involve Great Lakes water related problems. In Exhibit 1, Figure 1-2 shows the study area includes virtually all of the Eastern Interior coal province and most of the Appalachian coal province (excluding sections in Tennessee and Alabama).

The study was Congressionally mandated and conducted under the auspices of the US-EPA. The purpose of the study was to investigate the economic, social, health and other related impacts associated with proposed utility developments in the basin. The study was an integrated technology assessment where a set of scenario models were developed reflecting the implications of energy and economic developments in the basin to the year 2000. These results, in turn, were used as input to impact models to assess the significance of energy and economic developments. Within that context, the present research falls in the category of impact assessment. Exhibit 2 portrays the information flow within the overall ORBES project leading to this particular piece of research. The sequence of information flow in figure 2 is as follows: For specified conditions, the energy and fuel demand model provides consistent estimates of energy and fuel use in the region to the year 2000 [2].; energy and fuel use information is used by Teknekron Research, Inc. for purposes of estimating emissions and concentrations levels in the region out to the year 2000 [3]; emissions and concentrations information is used by The Institute of Ecology (TIE) to estimate the physical dose-response relationships (physical crop losses in the region out to the year 2000); finally, the physical crop loss information is used for purposes of estimating monetary losses to agricultural producers in the region [5]. Because of the charge given to the US-EPA, monetarized damages are broken out into those uniquely attributable to utilities and those attributable to other point sources in the region.

It is important to note that this type of design involves several pieces of research where error-bounds on results are largely unknown. It is also important to note, however, that one is really interested in comparing cases (scenarios), and as a result the absolute value of numbers may not be nearly as important as the comparison between numbers generated for different cases. The objective is to develop a comparative set of numbers in a consistent manner and in accordance with state-of-the-art modelling for each component of the integrated assessment.

In the case of monetarized agricultural damages, three scenarios, or possible sets of future events, were analyzed. They are as follows.

Scenario 2: This scenario represents a "business-as-usual" representation of economic and energy conditions in the region. The scenario assumes SIPs on existing units will be complied with and NSPS and RNSPS standards will be fully implemented for additions to generating capacity.

Scenario 2d: This scenario is identical to scenario 2 with respect to NSPS and RNSPS standards being met and with respect to the economic growth rate in the region. The scenario differs from scenario 2 in that we assume that SIPs are not complied with. Because this is the case, the scenario is more lax with respect to air quality than scenario 2.

Scenario 7: This scenario is identical to scenario 2 with the exception of two parameter values: The growth rate for electric capacity, 1976-2000, is higher than that in scenario 2 and plant life is assumed to be 45 years compared with 35 years in scenarios 2 and 2d.

When examining research results as between scenario 2 and 2d, information is obtained on differences in monetarized losses to agricultural producers from alternative policy assumptions concerning compliance or non-compliance with SIPs. Comparing scenarios 2 and 7, on the other hand, reflects differences arising from alternative assumptions concerning anticipated growth in the region as well as expected plant life for generating facilities.

Monetarized values for agricultural losses always refer to the ORBES portion of states, not to the complete states (Kentucky is the only exception).

SECTION III: PRODUCTION EXTERNALITIES

The charter materials distributed for these hearings suggests a high level of sophistication on the part of members and staff of the subcommittees. It is well, nonetheless, to remind those present of the nature of agricultural losses in the context of economic theory.

Combustion activities produce residuals which must appear in one or another physical form; gaseous, liquid, or solid. Depending on the form chosen, level of control, and the ability to dispose of waste, residuals may impose harmful effects on others in terms of health or damage to physical structures, crop growth, or several other things. To the economist, this situation is characterized as a "production externality." The nature of the problem is one in which producers generate some residual which does not enter into their cost calculations but which imposes harmful effects on others. The classic case (primary standards) is that of a combustion related activity generating airborne residuals which effect human health. The problem in dealing with such cases is that the private property system historically has not provided any way in which recipients may recover damages, nor any way to internalize to the producer emitting the residuals the social cost associated with this phenomenon. The Clean Air Act established a set of regulatory emission standards, promulated in terms consistent with existing research literature. Recent revisions of the Clean Air Act have introduced other institutional considerations suggesting alternative ways of dealing with the phenomenon. In particular, the 1977 Amendments to the Clean Air Act opened up the possibility of a political jurisdiction bringing suit against another political jurisdiction for using up ambient air levels on the part of the recipient. Similiarly, there is growing interest in the sale of "pollution rights" or other marketing devices designed to achieve optimal levels of pollution. It appears that there is a growing awareness that the allocation of pollution rights, which is the inverse of geographically disbursed damages, should be treated in an economically efficient way.

Of recent vintage, an additional suggestion for dealing with production externalities is the so called "bubble" concept. This notion is important insofar as it recognizes the regional nature of production externalities as well as the phenomena of long-range transport of airborne residuals. In large measure the growing interest in acid-rain is but one of several manifestations of the long-range transport phenomenon. Essentially, these findings suggest that airborne residuals are carried in the atmosphere long distances and are chemically converted (due to heat, moisture and sunlight conditions) into substances which are deposited in dry or wet form, far removed, producing harmful effects. An example of the potential harm which may result from long-range transport may be found in a recent study of the Columbus SMSA conducted for the US-EPA sponsored ORBES project [6].

The above provides some general groundwork for the remainder of this testimony. We are concerned with the damages which accrue to agricultural producers in the ORBES region associated with alternative scenarios of economic and energy and fuel delopments in the region, 1976-2000.

SECTION IV: RESEARCH METHODOLOGY

To properly estimate monetarized agricultural losses requires statistical estimates of demand and supply curves by crop, estimates of related sector activities such as agricultural transportation, fertilizer, etc., and costs associated with productivity enhancing adjustments. For purposes of this research, we're only able to estimate the direct losses to agricultural producers on the assumption that the producers faced fixed agricultural real prices over the 1976-2000 period. Ongoing work by one of my graduate students is supplementing this analysis for purposes of adding indirect costs; losses in transportation, fertilizer, and other sectors. The proper definition of losses in economic terms consists of producer and consumer surplus losses; in this case only consumer surplus losses as the real price of agricultural goods is invariant over time. Exhibit 3 displays the nature of loss estimation in this work. In Exhibit 3, curve S_o represents a pollution free supply curve for ORBES producers and P_o depicts the real price of agricultural goods. This figure is applicable to any of the three crops or areas examined in the study. The producer surplus area for a pollution-free environment would consist of the area aP_ob. The effects of SO_2 and O_3 concentrations within the region is to reduce productivity. The effect of this is to shift the supply curve leftward as illustrated in curve S_1. S_1, then, can be thought of as a dirty-air supply curve and producer surplus is measured by the area cP_od. The losses due to SO_2 and O_3 concentrations, then, consist of the difference in producer surplus measured as between the two curves; $aP_ob - cP_od = acdb$. It is this magnitude that we wish to measure annually over the period 1976-2000 for the ORBES scenarios. This is a correct measure on an annual basis of economic losses suffered by the agricultural sector from airborne residuals. It should be noted that a curve such as S_1 may shift to the right or left of the clean-air curve depending whether concentrations increase (a leftward shift) or decrease (a rightward shift).

In this analysis we assume regional producers are price takers. That is to say, producers operate in competitive markets so that variations in individual output levels do not influence market prices. Producer losses are discounted at a 10% rate and summed over the entire period in order to estimate the present discounted value of cumulative producer surplus losses. For comparative purposes, we also estimate the cumulative present discounted value, 1976-2000, of potential clean-air production on the assumption that the real price of agricultural goods is unchanged as is clean-air production. It should be noted that these calculations assume the following:

(1) prices of affected crops increase at the same rate as inflation and;

(2) the size of the regional agricultural sector is unchanged over time with respect to the affected crops.

The crops examined are corn, soybeans, and wheat and the pollutants of interest are SO_2 and O_3. To carry out the analysis described above requires several parameter estimates. We need estimates of the following:

(1) annual real prices of affected agricultural goods 1976-2000;

(2) output of affected crops over the same period;

(3) supply elasticities for each of the crops as well as the size of the regional agricultural sector with respect to these crops; and

(4) anticipated clean-air production and dirty-air production over the period 1976-2000.

The requirements defined above for clean-air and dirty-air production are provided by The Institute of Ecology [4] and are based upon ambient air quality in the region from Teknekron Research, Inc. (TRI) [3], which in turn is based upon estimates from the ORBES energy and fuel demand model over the same time period [2].

Complete details concerning the calculations as well as the values for real prices of affected goods, output of affected goods and supply elasticities may be found in the research document prepared by Page [5]. The associated physical crop loss information may be found in the TIE document [4] and the air information in the TRI document [3].

Existing literature did not contain adequate estimates of supply elasticities for our purposes. Because this is the case, we conducted our own investigations into supply elasticities for corn, wheat and soybeans in the ORBES region. These calculations are critical to our estimation of monetary losses as those losses, in a computational sense, are uniquely determined by the slope of those supply curves. The procedures used for estimation are standard [7] and produce statistically significantly results.

The procedure, then, is one which takes the physical crop losses, 1976, 1985 and 2000, provided by The Institute of Ecology and uses that information for purposes of estimating monetary producer surplus losses which are a measure of the welfare losses to the agricultural sector. This analysis is performed for each crop and each of the ORBES-portions of states falling within the region. We report information at the regional level, the ORBES-portion of each state, by crop, as well as the extent of losses attributable to SO_2 and O_3 and attributable to utility versus non-utility sectors.

SECTION V: RESULTS

Results of our calculations consist of a large number of tables reporting losses by crop, by state, by region, by type of pollutant and in terms of utility versus non-utility associated losses. It is not possible to report all of these findings during this testimony. Complete results may be obtained in the Page document [5]. We will focus here on the overall results as they pertain to the total region and the geographic distribution of losses within the region, by crop and particular pollutants.

Exhibits 4, 5 and 6 contain the results of our calculations for the case of probable crop losses.

Exhibit 4 reports the results of our calculations of monetarized agricultural losses for scenario 2. The value of losses is in millions of 1975 dollars. We also provide calculations of the percent losses are of pollution-free output over the 1976-2000 period as well as the percent losses are of the ORBES total losses by ORBES-related state areas. In the case of scenario 2, total regional losses constitute approximately 10.3% of the discounted value of pollution-free output over the 1976-2000 period. Those losses uniquely attributable to utilities constitute approximately 4.3% of pollution-free output. Losses are unevenly distributed with respect to the ORBES-related portion of each state. Illinois, which accounted for 53.6% of total regional losses, has the single largest loss within the region. This is followed by Indiana, with 25.1%, and then by Ohio with 13.9%. The remaining states constitute only a small fraction of the total regional losses from airborne residuals: Kentucky is 6.1%. Pennsylvania is 0.4% and West Virginia is 0.1%. For the base-case, then, the general conclusion is that total losses are on the order of 10.3% of pollution-free output, 1976-2000, and utility related losses are on the order of 4.3% Losses are unevenly distributed by the ORBES-related portions of the states forming the ORBES region.

Exhibit 5 contains results for Scenario 2d, which differs from scenario 2 only with respect to SIP standards. The loss pattern is almost identical to that of scenario 2. The total regional losses constitute 10.4% of the present discounted value of clean-air production and utility related losses 4.3%. As was the case with scenario 2, the distribution of losses is uneven with respect to the ORBES-related portions of states and is almost identical to that observed above for scenario 2. The conclusion, then, is that the compliance or noncompliance with SIPs does not significantly influence the degree of agricultural losses within the region nor within the ORBES-related portions of states within the region.

As noted earlier, scenario 7 differs from scenario 2 only with respect to the anticipated rate of growth in electric generating capacity and plant life. The effect of these two differences is to raise the percent losses are of pollution-free output from 10.3% in scenario 2 to 12.3% in scenario 7 (see Exhibit 6). The losses uniquely attributable to utilities similiarly rises from 4.3% to 5.5%. The distribution of losses by ORBES-related portions of states is comparable in magnitude to that observed in the case of scenarios 2 and 2d. The higher growth rate in capacity for scenario 7 produces the only case where agricultural losses, and hence monetary losses, increase over the entire 1976-2000 period. In scenarios 2 and 2d, losses increase our to 1984 and then decrease, 1985-2000. In the case of scenario 7, however, the higher growth rate in capacity generates physical losses, and hence economic losses, which rise throughout the period to 2000.

Examining Exhibits 4, 5 and 6, it will be observed that the overwhelming percentage of total dollar losses within the region are attributable to ozone concentrations: In the case of scenario 2, 99.3%; scenario 2d, 98.9%; and scenario 7, 99.4%. The reader is reminded that these ozone concentrations within the region are related to NO_x emissions. This finding is of some significance in that only in the case of Illinois are there SIP requirements concerning NO_x emissions. As a consequence, compliance or noncompliance (scenarios 2 and 2d compared) does not matter a great deal with respect to monetarized agricultural damages, although it does matter with respect to the level of SO_2 emissions. As SO_2 emissions account for only on the order of 1% of total monetarized agricultural losses within the region, the standards are of little significance. The conclusion, then, is that if agrucultural damages are of importance to those living within the region, efforts should be made to investigate the possibility of NO_x emission standards for SIP plants, as well as more stringent standards for NSPS and RNSPS plants.

The general conclusions which emerge from this research are as follows:

(1) Monetary losses to agricultural producers in the ORBES region tend to be on the order of 12% of the present discounted value of clean-air production;

(2) Similiarly defined losses from utilities are on the order of 4.8%;

(3) Losses are highly concentrated in the ORBES portions of Illinois, Indiana and Ohio;

(4) The overwhelming monetary losses are attributable to O_3 concentrations in the region;

(5) High growth in electric demand (scenario 7) produces annual losses which rise to the year 2000, while scenarios 2 and 2d tend to level off after 1985.

Aside, then, from the magnitude of losses which emerge from this research, the two additional points of interest relate to the effect on agricultural losses of high growth in electric generating capacity and to the fact that SIP standards do not include, for the most part, NO_x as a criterion pollutant.

SECTION VI: IMPLICATIONS OF RESULTS AND SUGGESTIONS FOR FURTHER RESEARCH

It is really not possible to compare our results with those obtained from previous research. Earlier work focused on southern California and utilized somewhat different methodologies. This fact alone is important as it highlights the need for a comprehensive research program carried out in a consistent way and for properly defined agricultural regions.

Our own results highlight the importance of NO_x emissions in the ORBES region and strongly suggest the need for evaluation of revised SIPs, NSPS and RNSPS standards. In addition, there is need for additional research on physical dose-response relationships to identify several important properties of the relationship between airborne residuals and crop damages. Among these needs are the following::

(1) The extent to which there exists long-term damage

associated with the effect on soil conditions from airborne residuals;

(2) the need to investigate the relative cost of productivity-enhancing treatment of crops in order to overcome physical damages associated with airborne residuals;

(3) the need to investigate synergistic effects associated with a variety of contaminants in the atmosphere.

With respect to the economic evaluation of crop losses, the following suggestions are appropriate:

(1) There is a need to recognize the regional characteristics of physical, and hence economic, losses from airborne residuals. That need would best be met by conducting a large scale research project using the same methodology and definitions across regions;

(2) Work consistent with the above suggestion should be carried out in terms of properly estimated regional supply and demand equations for the agricultural sector. It is almost certain that this will require original research;

(3) Work on regional losses should be conducted for both direct and indirect costs associated with airborne residuals. This will require a consistent methodology for the estimation of indirect losses. The most likely framework for such work would be a set of input-output tables which reflect, to the greatest extent possible, regional economies;

(4) The kind of research suggested above should be done in a way consistent with control technology research in order that benefits and costs may be properly compared for purposes of promulgating standards.

REFERENCES

1. Ohio River Basin Energy Study (ORBES) Main Report: Grant Numbers EPA R804816, R805585, R805588, R805589, R805590, R805603, R805608, R805609, R806451 and Cooperative Agreement Number EPA CR807395.

2. Walter P. Page, West Virginia University, and Doug Gilmore and Geoffrey Hewings, University of Illinois at Urbana-Champaign, An Energy and Fuel Demand Model for the Ohio River Basin Energy Study Region, Grand No. EPA R805585 and Subcontract under Prime Contract EPA 805588.

3. Vol. III. Teknekron Research, Inc., Selected Impacts of Electric Utility Operations in the Ohio River Basin (1976-2000): An Application of the Utility Simulation Model, Subcontract under Prime Contract EPA R805588

4. Orie Loucks, Thomas V. Armentano, Roland Usher, and Wayne Williams, The Institute of Ecology; Richard W. Miller, The Institute of Ecology and Butler University; and Larry Wong, Indiana University, Crop and Forest Losses Due to Current and Projected Emissions from Coal-Fired Power Plants in the Ohio River Basin, Subcontract under Prime Contract EPA R805588.

5. Walter P. Page, James Ciecka, and Gary Arbogast, West Virginia University, and Robert G. Fabian, Estimating Regional Losses to Agricultural Producers from Airborne Residuals in the Ohio River Basin Energy Study Region, 1976-2000, Grant No. EPA R805585 and Subcontract under Prime Contract EPA R805588

6. Walter P. Page and John Gowdy, West Virginia University, Gross Regional Product in the Ohio River Basin Energy Study Region, 1960-1975, Subcontract under Prime Contract EPA R805588.

7. M. Nerlove, Dynamics of Supply: Estimation of Farmers Response to Price, Johns Hopkins University Press, Baltimore, 1958.

EXHIBIT 1

Figure 1-1
Ohio River Basin Energy Study (ORBES) Region

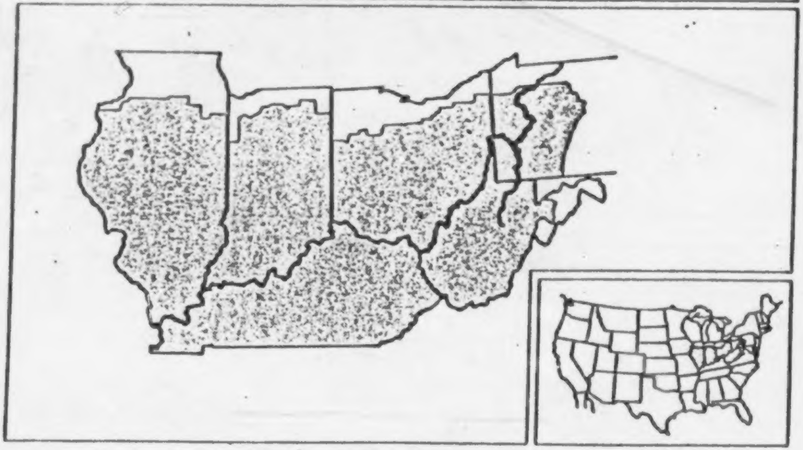


Figure 1-2
ORBES-Region Coalfields

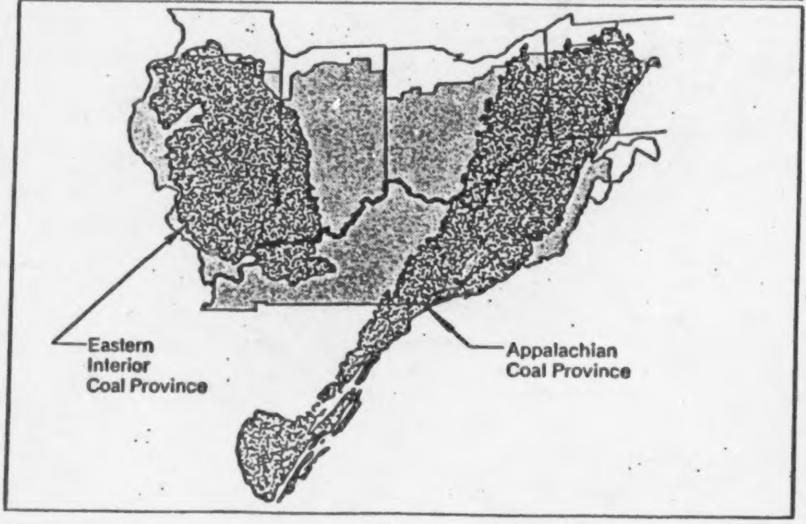

Eastern
Interior
Coal Province
Appalachian
Coal Province

EXHIBIT 2

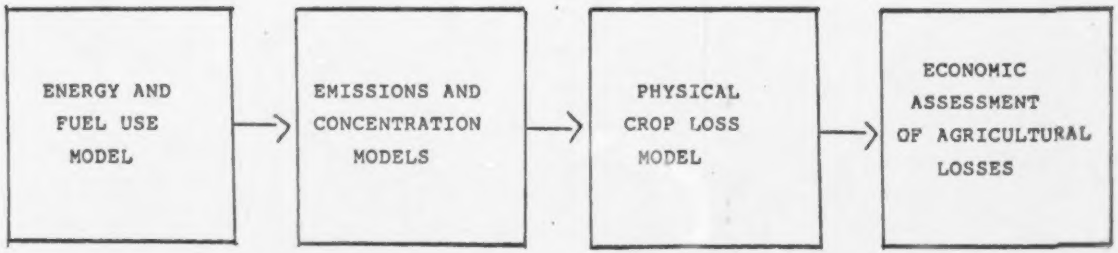

ENERGY AND FUEL USE MODEL
EMISSIONS AND CONCENTRATION MODELS
PHYSICAL CROP LOSS MODEL
ECONOMIC ASSESSMENT OF AGRICULTURAL LOSSES

FIGURE 3

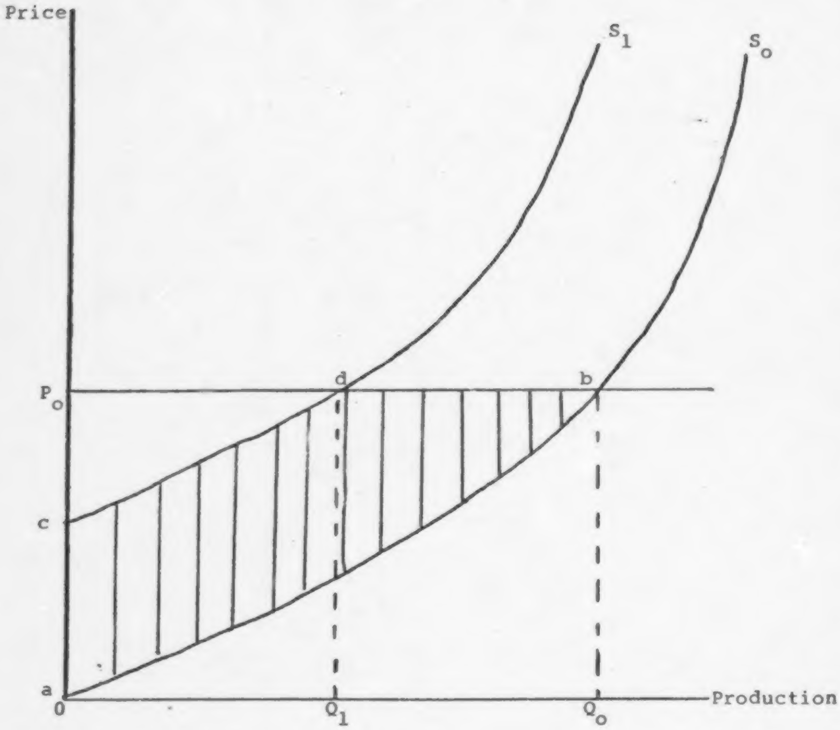


EXHIBIT 4

NET PRESENT VALUE OF PROBABLE TOTAL AND UTILITY-RELATED CUMULATIVE CROP LOSS, 1976 TO 2000, FROM SO_2 AND O_3: SCENARIO 2*

ORBES area	Losses[†] (millions of dollars)	Percent losses are of pollution-free output	Percent losses are of ORBES total losses[#]
IL	3755.56 (1565.78)	10.5 (4.4)	53.6 (53.8)
IN	1758.51 (727.60)	10.0 (4.1)	25.1 (25.0)
KY	479.76 (201.18)	10.6 (4.4)	6.1 (6.9)
OH	976.00 (403.18)	10.1 (4.2)	13.9 (13.8)
PA	27.71 (11.58)	7.6 (3.2)	0.4 (0.4)
WV	4.48 (1.91)	7.7 (3.3)	0.1 (0.1)
ORBES TOTAL	7002.03[&] (2911.22)	10.3 (4.3)	100.0 (100.0)

[*] Assumes a 10% discount rate. Numbers in parentheses are for utility-related losses.

[†] Crops are corn, soybeans, and wheat.

[#] Sum may notbe 100% due to rounding.

[&] SO_2 losses are .7% of total and O_3 99.3%.

EXHIBIT 5

NET PRESENT VALUE OF PROBABLE TOTAL AND UTILITY-RELATED CUMULATIVE CROP LOSS, 1976 TO 2000, FROM SO_2 AND O_3: SCENARIO 2d*

ORBES area	Losses[≠] (millions of dollars)	Percent losses are of pollution-free output	Percent losses are of ORBES total losses[#]
IL	3767.02 (1577.24)	10.6 (4.4)	53.6 (53.6)
IN	1771.41 (740.50)	10.0 (4.2)	25.2 (25.2)
KY	482.59 (204.01)	10.6 (4.5)	6.9 (6.9)
OH	977.96 (405.11)	10.1 (4.2)	13.9 (13.8)
PA	27.95 (11.82)	7.6 (3.2)	0.4 (0.4)
WV	4.51 (1.93)	7.8 (3.3)	0.1 (0.1)
ORBES TOTAL	7031.41[&] (2940.61)	10.4 (4.3)	100.0 (100.0)

* Assumes a 10% discount rate. Numbers in parentheses are for utility-related losses.

[≠] Crops are corn, soybeans, and wheat.

[#] Sum may not be 100% due to rounding.

[&] SO_2 losses are 1.1% of total and O_3 98.9%.

EXHIBIT 6

NET PRESENT VALUE OF PROBABLE TOTAL AND UTILITY-RELATED CUMULATIVE CROP LOSS, 1976 TO 2000, FROM SO_2 AND O_3: SCENARIO 7[*]

ORBES area	Losses[/] (millions of dollars)	Percent losses are of pollution-free output	Percent losses are of ORBES total losses[#]
IL	4491.960	12.6	53.7
	(1998.010)	(5.6)	(53.8)
IN	2090.910	11.8	25.0
	(924.048)	(5.2)	(24.9)
KY	574.604	12.7	6.7
	(256.996)	(5.7)	(6.9)
OH	1168.870	12.0	14.0
	(516.399)	(5.3)	(13.9)
PA	30.909	8.4	0.4
	(13.649)	(3.7)	(0.4)
WV	4.978	8.6	0.1
	(2.231)	(3.9)	(0.1)
ORBES TOTAL	8362.221[&]	12.3	100.0
	(3711.345)	(5.5)	(100.0)

[*] Assumes a 10% discount rate. Numbers in parentheses are for utility-related losses.

[/] Crops are corn, soybeans and wheat.

[#] Sum may not be 100% due to rounding.

[&] SO_2 losses are .6% of total and O_3 99.4%.

Mr. **Brown**. Thank you very much, Dr. Page.

Mr. Roberts, do you have any questions?

Mr. **Roberts**. Yes, Mr. Chairman, and I won't take much time. I am going to ask a parochial question. Could the results of this study be applied to any other region, say the high plains region?

Dr. **Page**. Not in my opinion.

Mr. **Roberts**. OK. Now, you have been to California and you have been to this area here, and I noticed on page 16 you said that it would be valuable to go ahead with this kind of study in other regions.

Dr. **Page**. Yes. I don't think these results are transferrable any more than southern California results would be transferrable to this region.

Mr. **Roberts**. I see. So I can't say to my Kansas farmers that if we don't get our SIP's straightened out with the ozone—and I have trouble with these acronyms; if I said that, they would think I would be talking about iced tea, I think, but——

Dr. **Page**. I am a graduate of the University of Kansas so I am somewhat familiar with your part of the world.

You can point out to them, it seems to me, that in one area of the country these are the kinds of losses which are experienced and even though work has not been done that includes the high plains, what we know from biologists convinces us that we might get results there of a comparable nature.

Mr. **Roberts**. I think it is the evaluation that I have a problem with. Of course, I have problems, I guess, with my own checkbook in terms of keeping that balanced, but what on page 8 here is a consumer surplus loss?

Dr. **Page**. I had hoped no one would ask that. I included that section of materials only for purposes of stating what is the appropriate way to evaluate losses to an economist. Producer and consumer surplus losses are the appropriate measure of monetary welfare losses to producers. I am having difficulty thinking of how to explain the notion, as it is a very difficult one.

Mr. **Roberts**. Let me go on just with a general question. I am just asking is it very realistic to assume that we can really predict the prices that farmers will receive up to the year 2000? If we can, I think we both ought to go and maybe apply for a position with the American Board of Trade and we could be much more successful than we are now.

When you said that you factored into your methodology here about farmers keeping pace with inflation, I was wondering about things like embargo or like yield or like all sorts of variables. I am just wondering. Or is this just a frame of reference whereby you have some numbers and then, over a period of time, you are saying it is 10 percent of that?

Dr. **Page**. Well, I didn't feel I was in a position to try to model the agricultural sector over time, so it was necessary that I do something different. I am well aware of the difficulties of modeling the agricultural economy.

Mr. **Brown**. That is what we call a simplifying assumption.

Dr. **Page**. Yes. So the price that is used was actually a weighted average price of, I believe, the past 10 years of prices of corn, soybeans, and wheat, and then I assumed that that real price remains constant.

Mr. ROBERTS. I am not trying to nitpick or find fault with your methodology. If I were a reporter, I would quickly turn to your summary and say that the farmers in Illinois are going to suffer billions of dollars in damage unless we get this under control, and that assumes when it hits the press that people will say it is a prediction as opposed to a frame of reference. I wanted to get that very clear in my mind.

Dr. PAGE. I think one thing that one can say is, if you do it this way, your error is probably on the downward side.

Mr. ROBERTS. I appreciate your testimony. Thank you.

Mr. BROWN. Dr. Page, there is one thing about your testimony that I don't quite understand. Your overall percentage figure of 10 percent is two or three times the figure used by previous witnesses and apparently the figure that other studies have come up to and, of course, none of them have had the same detailed approach to this as you have. They are educated guesses, I would say. But the figures of 2 to 4 percent were used for air pollution losses in agriculture, generally speaking, and you are using a 10 percent to 12 percent, depending upon the assumptions.

You built this up from a base of data supplied by biologists, this actual crop loss, which you then analyzed in terms of the economic impact. Can you throw some light on the discrepancy, as to whether it may be from the agricultural loss component or from the way in which you have been translating this into economic data?

Dr. PAGE. I suspect there are two or three important reasons for the differences. I think the 2 or 3 percent number that I have been hearing this morning is a national figure, so that is the value of all agricultural output. This, of course, is the value of losses and clean air production for only three crops in a small region. I don't know how they would compare.

Mr. BROWN. We would assume that this is a more highly polluted region than, say, the Great Plains.

Dr. PAGE. Much more.

Mr. BROWN. And that perhaps the impact on these three crops is greater than it would be on another range of valuable crops.

Dr. PAGE. There is another important reason for there being differences. The figures that we are hearing this morning of 2 and 3 percent relate to the losses in a recent year. Now, these numbers, of course, are cumulative numbers, losses over time, derived from some air quality models which tell me that NO_x emissions and O_3 concentrations are going to keep increasing over time.

Mr. BROWN. So the percentage increase would have gone up from the current stage.

Dr. PAGE. That is correct. If some of these others, for instance, used my same air data base and physical losses data base, I suspect after 1985 they would come up with a much larger percentage.

Mr. BROWN. Well, certainly your figures give us much greater cause for concern than the lower figures, which, you might say, might be tolerable, but a 10- to 12-percent loss in the three most important agricultural crops in this country, I think you might say, is a startling figure.

Dr. **Page**. I think so. That is why I really wanted to emphasize the policy implications, as I think these kinds of results do say a great deal for what we do with SIP's, NSPS, and RNSPS standards.

Mr. **Brown**. Well, you aren't making a very strong case for enforcing SIPs throughout the country but you are making a strong case for stiffer NO_x regulations.

Dr. **Page**. That is right, and to include NO_x emission standards in SIP's, which in five of these six States included in my work do not exist.

Mr. **Brown**. We are very grateful for your testimony, Dr. Page. It is extremely helpful to us and we appreciate it and I hope we can keep in touch with your research.

Dr. **Page**. Thank you for inviting me.

Mr. **Brown**. The subcommittee will be adjourned.

[Whereupon, at 12:37 p.m. the subcommittee adjourned, to reconvene at the call of the Chair.]

APPENDIX

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

AUG 17 1981

OFFICE OF THE
ADMINISTRATOR

Honorable James H. Scheuer
Chairman
Subcommittee on Natural Resources,
Agriculture Research and
Environment
Committee on Science and Technology
House of Representatives
Washington, D. C. 20515

Dear Mr. Chairman:

On July 9, 1981, your Subcommittee, along with the Subcommittee on Department Operations, Research, and Foreign Agriculture of the Committee on Agriculture, scheduled a hearing on the impact of air pollutants on agriculture. You requested that Dr. Jeffrey J. Lee of EPA's Corvallis Laboratory submit a statement for the record at a later date on the subject of the impact of acid deposition on agricultural production. Enclosed is the statement by Dr. Lee to be included in the record of your hearing.

We appreciate the opportunity to provide you with this statement. If I can be of further assistance, please contact me.

Sincerely yours,

Lewis S. W. Crampton
Acting Director
Office of Legislation

ACID DEPOSITION AND AGRICULTURAL PRODUCTION

Testimony Submitted to

Subcommittee on Natural Resources,
Agriculture Research and Environment
House Committee on Science and Technology

and

Subcommittee on Department Operations,
Research, and Foreign Agriculture
House Committee on Agriculture

by

Dr. Jeffrey J. Lee
Corvallis Environmental Research Laboratory
Office of Research and Development
United States Environmental Protection Agency
Corvallis, Oregon

ACID DEPOSITION AND AGRICULTURAL PRODUCTION

Jeffrey J. Lee

Summary

In the United States, commercial agricultural (non-livestock) crops have an annual farm value of over $55 billion. Pasture, grassland, and home-garden productivity add to this value. Not all of the agricultural lands of America are exposed to precipitation with a pH less than 5, but acid precipitation does fall on vast areas of highly productive croplands each year. Thus, there is considerable concern about its potential effects on crop productivity.

Experimental results from applications of simulated acid precipitation (as rain) suggest that while yield and quality of some crops may be affected, the responses are subtle and complex. Stimulatory, inhibitory, and null responses have been observed; for some crops, all three types of response have been noted, apparently affected by a range of environmental factors, including acid precipitation. Consequently, the net impact is best perceived as the result of competing positive and negative effects. Although the evidence at hand suggests that plus or minus changes in crop

yields are rather small, these changes could have economically important consequences for some crops because of its gross size and economic importance. Since a large part of the corn belt falls within an acid precipitation region, primary economic effects potentially could be significant, but many other factors would affect yield and economic effects. One experiment (see attachment 7) suggests but does not prove that, under some circumstances, acid precipitation can decrease the yield, increase the variability of productivity or decrease the marketability of important crops. Further experiments will be necessary before any conclusions can be drawn. In preliminary experimental studies, potentially adverse effects have been observed for field corn, soybeans, hay crops, wheat and potatoes, among others.

Crops-Effects research is needed to provide an economic assessment under current and potential future conditions of acid deposition. In addition to effects on crop growers, this economic assessment should include effects on those who utilize crops, e.g. livestock growers, food processers, and consumers. Research will be directed toward providing credible dose-response relations applicable over a range of acid deposition regimes and environmental conditions. Economic research should be initiated early to insure that the experimental data will be suitable for economic assessments, to explore ways in which existing data can be used for economic analysis and to identify and correct any gaps in economic assessment methodology.

Plant response to acid precipitation seems susceptible to, perhaps even dominated by, interactions with other environmental factors. It is thus essential to determine which factors have the greatest effects on yield-response to acid precipitation. The most urgent need is for data on the influence of rain characteristics (frequency, duration, intensity; within-event and event-to-event differences in concentrations of background and acid components.) Other potentially important abiotic interactions include soil fertility, water relations (including drought). Potentially important biotic environmental factors include symbionts, pathogens, insects, weeds, and soil organisms involved in nutrient dynamics. These factors are in addition to any intrinsic crop characteristics which influence response to acid precipitation. Identification of these factors, plus some understanding of the underlying mechanisms, is essential to the development of credible dose-response relationships.

Dose-response relationships will be considered realistic only if based on studies of field-grown crops. The intrinsic variability of field studies, compared to greenhouse studies, plus the complexity of potential interactions imply that a minimum of five growing seasons will be required for definitive studies. However, some important conclusions can be reached, and tentative conclusions made sooner. In this regard, EPA plans to conduct a critical assessment of the known effects of acid rain on agricultural crops in early FY 83; this assessment will determine the need and direction for future research.

Nature of Acid Deposition

Acid deposition consists of acid precipitation (rain, snow, fog) and dry deposition (gases, aerosols). I will limit my remarks primarily to acid precipitation.

Acid precipitation is precipitation which contains an excess of strong acid anions (primarily sulfate and nitrate) over basic cations (primarily calcium). The difference is made up of hydrogen ions; the greater the difference, the lower the pH. A decrease of one pH unit implies a ten-fold increase in hydrogen ions. The pH value below which the term "acid precipitation" is generally applied is for rainwater below pH 5.65 (the pH for equilibrium of water with atmospheric carbon dioxide). However, contamination by soil dust, organic matter, or other natural material could raise or lower the pH value. An annual average pH value of 5.0 seems appropriate for defining an acid precipitation region of interest to crop-effects research. Locations within this region would experience precipitation events below pH 5.0, including some unambiguously acidic events. Certainly, locations with an annual average pH of 4.7 would be well within the acid precipitation region.

This definition, plus data from the National Atmospheric Deposition Program (NADP, Attachment 1), indicates that the acid precipitation region contains all states east of the Mississippi River, plus Louisiana, Arkansas, Missouri, southern Iowa, and, possibly the eastern portions of Nebraska, Kansas, Oklahoma, and

Texas. Acid precipitation has also been documented in western California and Washington. In addition, there are localized acid precipitation areas within the remainder of the country.

The acid precipitation region thus contains some of the most productive cropland in the United States, including: a large portion of the corn and soybean regions; significant portions of the cotton, potato and apple areas; virtually all the tobacco, rice and peanut areas; and, probably, areas important for other crops (Attachment 3).

Acid precipitation varies temporally as well as spatially. In addition to the intrinsic variability of precipitation (frequency, duration, intensity of events), the chemical content of precipitation can vary. Changes can occur within events, from event-to-event, or seasonally. For example, summer rains tend to be more acidic than winter snows. In some areas, precipitation averages pH 3.8 or lower during the growing season. Individual events of pH 3.4 occur, with occasional events of pH 3.0 or lower.

In most places (except, possibly, California) sulfate dominates nitrate. Annually, sulfate accounts for twice as many hydrogen ions as does nitrate. During the growing season, this dominance increases to 3 to 1.

Crop-productivity Research

Research Results:

The effects of acid precipitation on crop-yield have been studied by applying simulated rain to plants. Major sites involved in EPA-funded crop-effects research are summarized in Attachment 2 and other study results are summarized in Attachment 3. No attempt has been made to include all research results in these tables. Instead, the range of statistically significant effects obtained at pH 3.0 or above for the 15 most important crops nationally are given. Effects are expressed as percent difference from control (i.e. non-acid rain) yield. If no statistically significant effects have been reported, then the "standard error of the difference" is given as a measure of range of effects.

Results of a 1979 survey of sulfuric acid rain effects on potted plants performed in Corvallis are summarized in Attachments 4, 5, and 6. Yield data from a 1980 field study involving both simulated sulfuric acid and sulfuric-nitric acid rains are summarized in Attachment 7.

Experimental studies are still at a preliminary stage. Thus, the results summarized in Attachments 3-7 are indicative, rather than definitive. The following should be kept in mind when referring to these tables:

1. Except for corn and for the decrease (-6%) for soybeans, the results given are for greenhouse-grown, rather than field-grown, plants. Sensitivity could be different in the two environments. In experiments in Corvallis, we have found a maximum effect on field-grown alfalfa of + 9%, rather than the + 31% cited in Attachment 3 for potted plants.

2. Except for corn and tomatoes, the results of Attachment 3 refer to sulfuric acid rain, rather than to the

sulfuric-nitric precipitation that is typical of ambient rain. Some experimental results suggest that the anion content may be as important as the pH of rain. We have found increased yield of field-grown alfalfa for sulfuric acid rain, but not for sulfuric-nitric acid rain. Preliminary results from Argonne National Laboratory suggest that the precise ratio of sulfate to nitrate can affect the response.

3. Although ambient acid rain varies in concentration, the experiments used constant pH treatments. Some researchers suspect that highly acidic events, occurring at sensitive stages of crop development, could be particularly harmful. However, neither the relevant rain characteristics (e.g. frequency, duration, acidity) nor the sensitive stages of development (if any) have been identified.

4. The response to acid precipitation probably depends on the concentrations of gaseous air pollutants. At Boyce Thompson Institute, the yield of field-grown soybeans was up to 26% greater at pH 3.4 than at pH 4.0 in the absence of ozone, but decreased by as much as 33% in the presence of low levels of ozone.

5. Other environmental factors may also influence the importance of acid rain effects. For example, we have found that acid rain can reduce root growth of hay and grain crops, thus possibly reducing drought resistance.

   Also, results from different experiments are sometimes contradictory, suggesting that some environmental factors may be strongly influencing acid rain response. For example, both increased and decreased soybean yield have been reported by Brookhaven and Boyce Thompson, while Argonne and North Carolina State University report no effects of simulated acid rain.

6. Virtually all studies have involved acid rain, rather than other forms of deposition.

7. For some crops (e.g. spinach, lettuce), foliar injury by acid precipitation can adversely affect marketability.

Despite the uncertainties, tentative theories of acid precipitation effects have been advanced by researchers. Acid precipitation response is perceived as the result of competing stimulatory and inhibitory effects; the balance between these determines whether the net response is positive or negative. This competition is complicated by the fact that acid precipitation has three major components - sulfate, nitrate, hydrogen ion.

The situation is further complicated by the fact that plants are multi-component systems (e.g. roots, stems, leaves). Acid precipitation may shift the allocation of photosynthate among these components, so that relatively more or less is put into the economically important plant part. Roots seem most susceptible to adverse effects.

Finally, the harvested portion may itself have components which are affected differently by acid precipitation. For example, the weight of grain is the product of the number of seeds and the weight per seed; these frequently respond in opposite directions.

The net result is that dose-yield relationships probably are a series of peaks and valleys, the location of which depends on other environmental factors. It is not known which factors most influence response, nor which tendencies dominate under commercial field conditions.

Research Program:

The overall objective of crop-effects research is to provide an economic assessment of the effect of acid precipitation under current and potential future conditions: To accomplish this, research should be directed towards providing credible dose-response relations applicable over a range of pH, nitrate, and sulfate levels, and environmental conditions. First, broad-brush studies are needed to determine those crops and environmental interactions (biotic, abiotic) most likely to produce positive and negative economically important effects. These results should then be used to select crops and experimental regimes for detailed studies leading to credible dose-response relations. Economic research should be initiated during the early stages to (1) insure that experimental data will be suitable for economic assessments, (2) explore ways in which existing data can be used in economic analyses, and (3) identify and correct any gaps in economic assessment methodology.

Little is known about the evironmental factors which influence crop response to acid precipitation. The most urgent need is for data on the influence of hydrologic characteristics (frequency, duration, intensity; within event and event-to-event differences in chemical composition) on precipitation characteristics. This knowledge is essential for extrapolation from experimental to ambient conditions. Some preliminary progress should be made by early FY 83. Other potentially important interactions include soil fertility, water relations, and other pollutants (gases, trace metals). Air pollutant-acid rain studies currently in progress should allow an assessment of the probable importance of this interaction by early FY 83. Knowledge of the other intractions will be sketchy at best, and knowledge of potential biotic interactions (e.g. disease, insects, weeds) will be virtually non-existent. Some economic research is currently being undertaken. The framework for economic assessment will be developed by early FY 83, at least to the point of indicating the adequacy of existing data and methodology. The current research supported by federal agencies and the Electric Power Research Institute should result in more certain answers over the next five years. Because of the complexity of the research problem, and because of the uncertainties involved in field studies, it would be difficult to shorten the required time for definitive results. However, it may be possible to reach some important tentative conclusions on crop-effects and research needs early in FY 83.

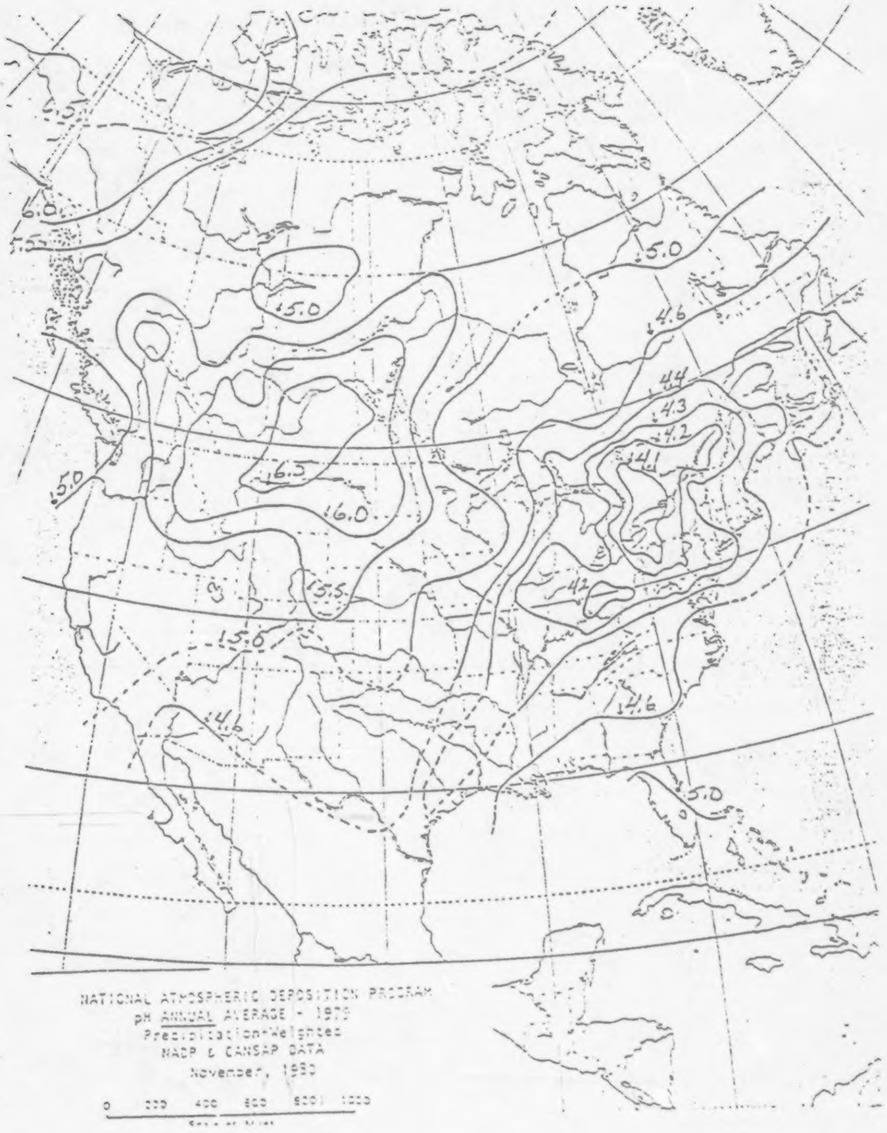
If this assessment in FY 83 indicates that crop-effects are relatively insignificant, the need for additional crop research may be less urgent than now. However, if the effects are significant, additional research will be necessary to develop definitive estimates of national economic impact. This is because empirical relationships which will result from experimental studies may lack credibility in both the scientific and non-scientific communities. In particular, extrapolation from experimental to realistic situations will be questioned unless scientists understand the underlying biological basis for observed yield responses and biotic/abiotic interactions. Research on these basic questions could become more important in future years, if experimental results indicate that acid precipitation probably has an adverse effect on crops.

Economic Impacts

Current knowledge is inadequate to support a conclusion that acid precipitation does or does not significantly affect the yield (quantity and/or quality) of commercially grown crops. Data are scarce or lacking for important crops. For example, results on field corn (Attachment 3) are from one site for one growing season; this study is continuing. However, the experimental observation of decreases in yield or marketability suggests that some crops may be adversely affected at economically important levels, although probably not at catostrophic levels.

By reducing supply, loss of productivity could increase prices for farm products. It is not clear that these increases would totally offset the loss of farm income from lower productivity. Farmers outside the affected area could benefit from those increased prices, but possibly at the expense of the affected farmers.

One large source of uncertainty in evaluating effects is that, on the time-scale of changes in agriculture, acid precipitation is not a new phenomenon. It is possible that agriculture has adapted by, for example, switching to varieties which are less sensitive to acid precipitation. If this has occurred, then the varieties currently being grown are not necessarily those which would be most productive under less acidic conditions.


5.5
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NATIONAL ATMOSPHERIC DEPOSITION PROGRAM
pH ANNUAL AVERAGE - 1979
Precipitation-Weighted
NADP & CANSAP DATA
November, 1980
0 200 400 600 800 1000
Scale of Miles

Attachment 2. Major sites involved in acid precipitation crop effects research.

Site	Contact
Argonne National Laboratory (Illinois)	Patricia Irving
Boyce Thompson Institute at Cornell (New York)	Jay Jacobson
Brookhaven National Laboratory (New York)	Lance Evans
Corvallis Environmental Research Laboratory (EPA) - Oregon State University	Jeffrey Lee
North Carolina State University	Walter Heck

Attachment 3. Summary of experimental yield-effects observed for 15 most important crops. (Source: Soybeans, Brookhaven National Laboratory; tomato ~~decrease~~, Oak Ridge National Laboratory; all others, Corvallis Environmental Research Laboratory)

Crop	1977 Farm Value Billion Dollars[a]	Importance in Acid Precipitation Region	Range of Experimental Yield-Effects for pH $\leq$ 3.0 % Difference from Control	Field Studies
Corn for grain	12.9	+	- 9 to 0	Y,C
Soybeans for beans	9.9	+	- 6 to + 11	Y,C
Hay (all types)	6.8			
Alfalfa		√	0 to + 31	Y,C
Timothy		+	0 to ± 24	N
Clover		+	0 ± 6[f]	N
Wheat	4.7	√	0 ± 8[e]	C
Cotton lint	3.6	√	N D	N
Tobacco	2.2	+	0 ± 4[d,f]	N
Sorghum for grain	1.4	+ b	N D	N
Potatoes	1.3	+	- 8 to + 11[e]	C
Tomatoes	0.9	+ c	-22 to + 31[d,e]	C
Rice	0.9	+	N D	N
Oats	0.9	-	0 ± 7[c,f]	N
Peanuts for nuts	0.8	+	N D	N
Barley	0.7	-	0 ± 7[e,f]	C
Apples	0.7	+	N D	C
Sugarbeets	0.7	+ c	N D	N

a. Source: Statistical abstract of United States (1978).
b. Primarily east Texas.
c. Primarily California.
d. Produce disfigured by simulated acid precipitation.
e. Decreased root growth observed.
f. No significant effects observed. Range is ± standard error of difference.
+ Nationally important production in region.
√ Locally important areas of production within region.
- Minor importance in region.
N D No data reported from greenhouse or field study.
Y Data available from field study.
N No data available from field study.
C Field study currently being performed at one or more sites.

Table 6. Yield of Marketable Portion of Crops Grown in 1979

Crop	Fresh Weight of Yield Per Pot						Dry Weight of Yield Per Pot					
	Control Mean^a g/pot	Ratio of Treatment Mean^a to Control Mean			SE^c	F-test Sig'n Level^d	Control Mean^a g/pot	Ratio of Treatment Mean^a to to Control Mean			SE^c	F-test Sig'n Level^d
		pH 3.0^b	pH 3.5^b	pH 4.0^b				pH 3.0^b	pH 3.5^b	pH 4.0^b		
Radish 1	43.23	0.44§	0.83§	0.92	0.04	0.000§	2.66	0.45§	0.79§	0.86†	0.04	0.000§
Radish 2	42.12	0.40§	0.81†	0.84*	0.06	0.000§	2.51	0.47§	0.83†	0.86*	0.05	0.001§
Radish 3	47.74	0.24§	0.73§	1.14*	0.06	0.000§	2.53	0.31§	0.77§	1.15*	0.05	0.000§
Radish 4	26.79	0.30§	1.03	0.86	0.09	0.000§	1.71	0.42§	1.01	0.87	0.08	0.000§
Radish 5	18.07^g	0.59	1.41	1.56	----^g	------^g	1.08^g	0.64	1.40	1.52	----^g	-----^g
Beet	55.07	0.57§	1.02	1.09	0.11	0.011†	10.38	0.55†	1.03	1.10	0.11	0.012§
Carrot	130.54	0.56§	0.55§	0.73†	0.08	0.001§	13.36	0.53§	0.57§	0.69§	0.08	0.000§
Mustard Green	59.28	0.70§	0.87*	0.83†	0.05	0.003§	7.30	0.69§	0.90	0.86*	0.06	0.002§
Spinach	32.33	0.85	0.99	0.90	0.07	0.388	3.58	0.93	1.01	0.99	0.08	0.871
Swiss Chard	99.72	0.90	1.04	0.94	0.07	0.561	16.66	0.98	1.04	1.03	0.06	0.827
Bibb Lettuce	129.97	1.01	1.02	1.03	0.04	0.932	6.13	1.05	0.97	1.07	0.01	0.087*
Tobacco	------	----	----	----	----	-----	27.64	0.97	0.97	1.03	0.03	0.443
Cabbage	240.01	0.91	1.47	1.01	0.17	0.131	29.09	0.87	1.19	0.92	0.13	0.178
Broccoli	44.63	0.75§	0.92	0.89	0.07	0.063*	6.07	0.75§	0.85	0.91	0.06	0.078†
Cauliflower	69.62	1.03	1.46	1.20	0.15	0.185	6.36	1.01	1.39	1.27	0.13	0.164
Potato	691.79	0.97§	1.11†	1.07*	0.03	0.001§	149.53	0.96§	1.05	1.05	0.03	0.000§
Green Pea	21.55	1.04	0.98	1.05	0.04	0.674	4.21	1.06	0.97	1.06	0.06	0.547
Alfalfa^e	------	----	----	----	----	-----	20.72	0.94	1.31§	1.17§	0.05	0.000§
Red Clover^e	------	----	----	----	----	-----	31.05	0.99	1.01	1.02	0.04	0.911
Tomato^e	302.80	1.31§	1.01	0.95	0.07	0.001§	------	----	----	----	----	-----
Green Pepper^e	193.12	1.05	1.20†	1.05	0.06	0.103*	12.72	1.13	1.17†	1.06	0.06	0.707
Strawberry^e	113.04	1.72§	1.72§	1.51§	0.13	0.001§	------	----	----	----	----	-----
Oats	------	----	----	----	----	-----	31.41	0.92	1.00	1.00	0.05	0.500
Wheat	------	----	----	----	----	-----	29.30	0.97	0.98	0.98	0.06	0.976
Barley	------	----	----	----	----	-----	34.71	1.05	1.06	1.00	0.05	0.727
Corn^f	------	----	----	----	----	-----	35.56	1.13*	0.95	0.99	0.05	0.085*
Onion	410.11	1.01	1.12	1.04	0.06	0.426	29.11	1.10	1.14	1.09	0.06	0.295
Fescue^e	------	----	----	----	----	-----	25.25	0.96	1.07	0.92	0.04	0.018†
Orchardgrass	------	----	----	----	----	-----	22.47	1.23†	1.10	1.00	0.07	0.097*
Bluegrass^e	------	----	----	----	----	-----	12.81	0.98	0.94	1.00	0.05	0.775
Ryegrass^e	------	----	----	----	----	-----	20.24	0.99	0.98	0.96	0.03	0.767
Timothy	------	----	----	----	----	-----	21.07	1.24†	1.09	0.86	0.07	0.003§

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[a] Sample size per mean: for SR and IR chambers, 14 pots; for SQ chambers, 25 pots (see Table 5 for chamber types).

[b] Significance of difference between acid rain treatment mean and control mean determined by two-sided t-test.

[c] Standard error of the mean (computed using error mean square from analysis of variance), divided by mean control yield.

[d] Significance level of F-test from one-way analysis of variance among four experimental groups.

[e] Seasonal total of multiple harvests.

[f] For corn, data refer to total aboveground (stem plus leaves) weight.

[g] Unreliable data for control; see text.

* Significant with $p \leq 0.10$.

† Significant with $p \leq 0.05$.

§ Significant with $p \leq 0.01$.

ATTACHMENT 4
FROM: LEE ET AL., ENV. AND
EXP. BOTANY 21:171-185.

Table 7. Dry Weights of Aboveground Portions and Roots of Crops Grown in 1979

	Total Aboveground Portions						Roots					
	Control Mean[a]	Ratio of Treatment Mean[a] to Control Mean					Control Mean[a]	Ratio of Treatment Mean[a] to to Control Mean				
Crop	g/pot	pH 3.0[b]	pH 3.5[b]	pH 4.0[b]	SE[c]	F-test Sig'n Level[d]	g/pot	pH 3.0[b]	pH 3.5[b]	pH 4.0[b]	SE[c]	F-test Sig'n Level[d]
Radish 1	1.94	0.84†	0.94	1.07	0.05	0.019†	2.66	0.45§	0.79§	0.86†	0.04	0.0006§
Radish 2	1.65	0.88	0.96	0.99	0.06	0.461	2.51	0.47§	0.83†	0.86*	0.06	0.001§
Radish 3	2.00	0.66§	0.84§	0.92	0.04	0.0009§	2.54	0.31§	0.77§	1.15*	0.05	0.0009§
Radish 4	1.55	0.86*	1.02	0.86*	0.05	0.066*	1.71	0.42§	1.01	0.87	0.08	0.0006§
Radish 5	1.29[e]	1.12	1.19	1.11	----[e]	-----[e]	1.08[e]	0.64	1.40	1.52	----[e]	-----[e]
Beet	10.03	0.90†	1.08	1.00	0.03	0.015†	10.39	0.55†	1.03	1.10	0.11	0.012†
Carrot	8.39	0.67§	0.69*	0.82	0.07	0.002§	13.36	0.54§	0.57§	0.69§	0.08	0.0009§
Mustard Green	7.30	0.69§	0.90	0.86*	0.05	0.002§	2.06	0.86	0.90	1.05	0.08	0.314
Spinach	4.23	0.95	1.06	1.02	0.08	0.818	1.63	0.86	0.99	1.09	0.15	0.740
Swiss Chard	16.66	0.98	1.04	1.03	0.06	0.827	13.35	0.90	0.99	0.96	0.11	0.596
Bibb Lettuce	6.13	1.05	0.97	1.07	0.03	0.087*	1.33	0.78§	0.88	0.94	0.06	0.074*
Tobacco	44.12	0.96	1.00	1.03	0.04	0.585	9.10	1.13	1.12	1.18	0.07	0.348
Cabbage	72.96	0.95	0.90	0.89	0.05	0.303	14.16	1.17	0.83	0.91	0.12	0.297
Broccoli	35.74	0.95	1.09	0.97	0.06	0.400	12.27	1.20	0.85	0.81	0.10	0.016§
Cauliflower	30.92	1.10	1.10	1.12	0.05	0.391	6.29	1.18	1.12	1.04	0.08	0.362
Potato	11.14	0.97	1.27§	1.24§	0.06	0.001§	3.71	0.68§	0.81†	0.98	0.07	0.005§
Green Pea	24.81	0.96	1.01	1.02	0.02	0.242	2.23	1.06	0.97	0.91	0.05	0.202
Alfalfa	33.83	0.94	1.30§	1.16†	0.05	0.0005§	19.72	1.00	1.17§	1.02	0.04	0.003§
Red Clover	37.04	1.00	1.04	1.04	0.04	0.824	7.37	1.05	1.03	1.11	0.05	0.394
Tomato[f]	34.49	1.04	1.12§	1.11§	0.03	0.026†	5.06	0.85§	1.01	0.98	0.04	0.029†
Green Pepper[f]	9.26	0.85*	1.14§	1.09	0.04	0.0006§	5.70	0.92	1.02	1.29	0.05	0.111
Strawberry[f]	40.01	1.17§	1.21§	1.13†	0.04	0.001§	36.17	0.86†	0.79§	0.99	0.06	0.016†
Oats	63.29	0.96	1.02	1.00	0.04	0.847	3.78	1.16	1.60§	0.97	0.16	0.027†
Wheat	69.73	0.98	0.94	0.98	0.05	0.850	11.45	0.64§	0.53§	0.71§	0.07	0.0009§
Barley	63.81	1.04	1.09	1.01	0.05	0.481	6.35	0.88	0.96	1.13	0.08	0.164
Corn	35.56	1.13*	0.95	0.99	0.05	0.085*	6.36	1.12	0.97	1.03	0.07	0.430
Onion	15.54	1.30§	1.08	0.94	0.07	0.007§	-----	-----	-----	-----	-----	------
Fescue	30.58	0.95	1.05	0.93	0.03	0.049†	21.48	0.87§	1.01	0.85†	0.05	0.005§
Orchardgrass	22.47	1.23†	1.10	1.00	0.07	0.097*	14.74	1.36§	1.00	0.68§	0.09	0.0009§
Bluegrass	16.43	0.96	0.91	0.96	0.06	0.530	6.48	0.92	0.85	0.75	0.10	0.130
Ryegrass	26.69	1.01	1.03	0.98	0.02	0.500	37.38	0.86†	0.84†	0.86§	0.05	0.093*
Timothy	21.07	1.24†	1.09*	0.86	0.07	0.003§	13.28	1.16	0.95	0.88	0.09	0.133

[a] Sample size per mean: for SR and LR chambers, 14 pots; for SQ chambers, 25 pots (see Table 5 for chamber types).
[b] Significance of difference between acid rain treatment mean and control mean determined by two-sided t-test.
[c] Standard error of the mean (computed using error mean square from analysis of variance), divided by mean control weight.
[d] Significance level of F-test from one-way analysis of variance among four experimental groups.
[e] Unreliable data for control; see text.
[f] Aboveground portion does not include weight of fruit.
* Significant with p ≤ 0.10.
† Significant with p ≤ 0.05.
§ Significant with p ≤ 0.01.

ATTACHMENT 5

Table 9. Relative Ratings of Maximum Acid Rain Injury of Leaves for 1979

	Acid Rain Injury by pH of Treatment		
Crop	3.0	3.5	4.0
Radish 1	++	+	o
Radish 2	++	+	o
Radish 3	+	+	o
Radish 4	+	+	o
Radish 5	+	+	o
Beet	+	+	+
Carrot	+	o	o
Mustard Greens	++	+	o
Spinach	++	+	o
Swiss Chard	++	+	+
Bibb Lettuce	+	+	o
Head Lettuce	+	+	o
Tobacco	+	+	o
Cabbage	+	o	o
Broccoli	+	+	o
Cauliflower	++	+	o
Potato	+	+	o
Green Pea	+	+	o
Peanut	+	+	o
Soybean 1	+	+	+
Soybean 2	+	+	o
Soybean 3	+	+	o
Soybean 4	+	+	o
Alfalfa	+	+	o
Red Clover	+	+	o
Tomato	++	+	o
Cucumber	++	+	o
Green Pepper	++	+	+
Strawberry	+	o	o
Oats	o	o	o
Wheat	o	o	o
Barley	o	o	o
Corn	+	o	o
Onion	o	o	o
Fescue	+	+	o
Orchardgrass	+	+	o
Bluegrass	+	+	+
Ryegrass	+	+	o
Timothy	+	+	o

++ At least half the plants had 10% or more of leaf area injured by acid rain at some time during growth.

+ Acid rain injury noted, but at no time during growth did more than half of plants show 10% or more of leaf area injured by acid rain.

o No apparent acid rain injury on leaves.

Table 4. Yields of field-grown crops receiving acid rain.

Crop	Fresh Weight of Yield per Plant: From Control Plants g	Fresh Weight: From Treatment Plants Ratio to Control Yield pH 3.0	pH 3.5	pH 4.0	S.E.[c]	Sig'n[b] Level	Dry Weight of Yield per Plant: From Control Plants g	Dry Weight: From Treatment Plants Ratio to Control Yield pH 3.0	pH 3.5	pH 4.0	S.E.[c]	Sig'n[b] Level
2:1 Sulfuric-Nitric Acid Rain												
Radish	13.06	0.86	1.00	0.99	0.04	0.14	0.64	0.92	1.03	1.04	0.03	0.11
Mustard green	139.00	0.67‡	0.86	0.69†	0.07	0.03†	8.05	0.78*	0.90	0.72†	0.07	0.09*
Spinach	56.51	0.92	0.93	0.85	0.10	0.78	3.84	0.99	0.97	0.89	0.08	0.78
Alfalfa	----	----	----	----	----	----	760.95[a]	1.03	1.02	1.05	0.03	0.62
Fescue	----	----	----	----	----	----	975.13[a]	0.96	0.97	1.00	0.05	0.89
Corn	----	----	----	----	----	----	154.58	1.00	0.96	0.91†	0.02	0.05†
1:0 Sulfuric-Acid-Only Rain												
Radish	11.38	0.95	1.25†	1.15	0.08	0.08*	0.59	0.93	1.15	1.13	0.07	0.13
Mustard green	127.83	0.77	0.96	0.96	0.07	0.16	7.40	0.84	0.95	0.97	0.06	0.24
Spinach	36.43	0.91	0.93	0.94	0.08	0.86	2.46	1.04	0.99	0.93	0.07	0.79
Alfalfa	----	----	----	----	----	----	815.78[a]	0.98	0.97	1.09†	0.02	0.01‡
Fescue	----	----	----	----	----	----	817.43[a]	1.06	1.19†	1.24‡	0.05	0.02†

[a] Dry weight of yield per (approximately) 18 ft² plot.

[b] Significance level of F-test for treatment effects.

[c] Standard error of the mean divided by mean control yield.

*Significant effect with $p \leq 0.10$.

†Significant effect with $p \leq 0.05$.

‡Significant effect with $p \leq 0.01$.

ANSWERS TO QUESTIONS—DR. HEGGESTAD

DECREASE IN FOLIAGE INJURY

A. Reasons for decrease.

1. SO_2 levels are significantly reduced near major industrial sources due to dispersion from tall smoke stacks and to reduction in emissions because of lower sulfur content of fuels and improved technology to remove SO_2.

2. Ozone injury is now recognizable by many growers and agriculturists. Where problems with ozone-injury have been identified, there has been increased use of tolerant cultivars.

B. Have crop losses increased or decreased over these two decades?

1. There has been observable decrease in losses on species such as tobacco where the leaf is the commercially valuable product. This is due to increased availability and use of tolerant cultivars.

   However, on most species where yield of grain or fruit is involved it is only in the last 5 years, approximately, that we have some measure of air pollution impact. We have learned there can be significant yield loss with minimal leaf injury; sometimes only premature aging of leaves. The typical acute injury caused by O_3 or SO_2 on foliage may be absent or much reduced.

ASSESS IMPACT OF AIR POLLUTANTS

A. If yield losses are below 10%, it is more difficult to determine whether air pollutants have a significant impact on yield. It is possible with a crop such as snap beans which can be grown to maturity in two months permitting two crops each year, to show over a five-year period that significant yield losses of only 4% may occur. (See attachment Atmospheric Environment 14: pp. 317-326. 1980).

B. Field research using open-top chambers will allow quantitative assessments below 10% if the experiment is set up to permit a regression analysis. If the correlation between pollutant dose and the yield loss is linear and highly significant as found in our mixed gas (O_3 plus SO_2) studies, we can quantify yield losses which are less than 10% (see figures 2 and 3 and the figure I prepared from Oshima's results in California and presented during the Hearings.).

NATIONAL CROP LOSS ASSESSMENT NETWORK

A. No there has not been enough time to evaluate the effectiveness of NCLAN to assess air pollution impact. Significant progress has been made. It takes time to get a program of this size fully coordinated so results from different locations are comparable. The quality assurances required by EPA will do much to improve the data. However, compliance means more and better instrumentation and more technical support. This increases the cost of the research. We are securing equipment to automate data logging but do not have such a system in operation as yet.

B. Much improved and useful data will be available in two years, but "conclusive results" will require more time, at least five years.

OXIDANTS REDUCE YIELD

A. & B. Elevated Oxidants?

At Beltsville, Maryland, concentrations of ozone exceed 0.10 ppm from about 5 to 40 hours during the summer season, and maximum hourly values may reach about 0.17 ppm during the season. There have been reports of 0.23 and 0.26 ppm in the Washington area during the past decade. Ozone values at Beltsville are believed to be fairly representative of ozone values along the Atlantic Coastal area from Connecticut to Virginia.

OZONE AND SULFUR DIOXIDE REDUCE YIELD

A. With snap beans at Beltsville and red kidney beans in the L.A. Basin, there was a significant interaction between SO_2 and O_3 in reducing yield. This occurs at an oxidant (ozone) dose which is near the threshold for reducing injury without added SO_2. With tomato at Beltsville and the L.A. Basin, the effects of mixtures of SO_2 and O_3 on yields were additive but not more than additive as on the species Phaseolus vulgaris, snap beans and red kidney beans. I do not know of comparable data for other species; however, a look at recent data obtained at the Argonne National Laboratory (Phytopathology 70: 1124-1133, 1980) suggests to me that the effects of low doses of SO_2 on yields of soybeans was due in part to presence of elevated ozone. Our current (NCLAN) research (1981), and at Raleigh, NC, involves additions of SO_2 and O_3 on soybeans. We should know considerable about the response of soybeans after the summer experiments are concluded.

B. In our experiments, we have added SO_2 to nonfiltered ambient air containing no additional O_3. Our lowest SO_2 dose in 1979 was .05 ppm for 6 hrs. a day, 5 days per week and in 1980, it was .06 ppm for 5 hrs a day; 5 days per week.

In 1981, we will use as the lowest dose .03 ppm for 4 hrs a day for 7 days a week. If converted to a 24 hr day average, I believe these levels exist in some areas of U.S. We need a better sort of the SO_2 air monitoring data than now exists to know how relevant our exposure doses are to those measured at various locations in the Unted States. We also need to conduct experiments such as described in the research need number 2 on page 8 of my statement.

C. I think the data base is inadequate to estimate crop yield losses. The best figure is for snap beans.

D. The NCLAN research program involves increasing doses of SO_2 and O_3 singly and in combinations. Predictive capability will be improved when the results two years or more of this research is available. Also, crop losses can be reduced significantly by plant breeding research. This has been very beneficial with tobacco which is about the only species where a concentrated effort in improving the resistance of cultivars has been made. We know that plant breeding research with other species such as alfalfa, potatoes and cotton have resulted in more tolerant cultivars although breeders for the most part were unaware of air pollution stress. The potential exists for increased air pollution tolerance along with suitable agronomic and horticultrual characteristics. The potential for change is less with perrenials as stated on page 11 of my testimony.

(I appreciate the opportunity to provide these answers to your questions as well as to provide testimony at the July 9 Hearings.)

ANSWERS TO QUESTIONS—DR. HECK

Responses to Questions Raised by Dr. James Greene

(Joint Hearing on The Impact of Air Pollutants
on Agricultural Productivity: Research on
Ozone and Sulfur Dioxide July 9, 1981)

Synergism - O_3 Combined With Other Pollutants

1. On page three you state, "ozone alone or in combination with sulfur dioxide and/or nitrogen dioxide is responsible for up to 90% of the air pollution caused crop loss in the United States."

   A. Does this mean that the interaction of ozone with other air pollutants is a major cause of crop damage in the United States?

   This is not a known fact because the data to support the statement is lacking. It is my belief that this is true, if air quality monitoring for SO_2 and NO_2 show that these two gases occur over a broad area at concentrations from 0.01 to 0.03 ppm for 40 to 60% of the time. If this does not occur, then the two gases would be less important.

   B. Are there other air pollutants that might react with ozone and cause significant crop damage in the future?

   Yes, but in a biological not a chemical sense. Data from Boyce Thompson Institute already implicates acidic precipitation. There is a good possibility that increasing CO_2 levels could interact with O_3 and cause a plant response. These are the two most likely candidates, at this time, that would affect national production.

Ozone Standard

2. On page 4 you say "The current ozone standard of 0.12 ppm for one hour is not protective of crops but may be realistic when comparing costs of controls with benefits of control."

   A. Do you have an estimate of the cost to protect crops if the ozone standard is lowered?

   No. This would reflect cost of emission control. The EPA should have a number of studies on these costs.

   B. If the standard is raised to a higher level, what impact will this have on crops? on economic loss?

   Data in reference 2, that I supplied, can be used to calculate the increased cost if the standard is raised. The costs would double with a 50 percent increase in the seasonal mean of the 7 hr/day maximum value.

Economic Loss From Ozone

3. On page 5 your experiment to analyze yield reductions of crops at different average seasonal ozone concentrations suggests that yield losses could be as high as $3.02 to 4.18 billion.

   A. You indicate your estimate is high by 50%, why?

      The estimate assumes equal sensitivity of crops to O_3 across the U. S. We know crops in the west are less sensitive because sensitivity decreases under dry (drought) conditions. The 50% figure seems a reasonable one to use to account for variable environmental conditions through the growing season with a major effect in the west.

   B. Does your estimate include crop loss in forest yields? If not, would not the impact of forests increase the damage estimate?

      No. Yes, but we have no good data base for this.

Economic Losses From Sulfur Dioxide

4. On page 6 you indicate crop losses from sulfur dioxide may be as high as $20 million per year.

   A. Will the combined effect of sulfur dioxide with other pollutants increase the crop losses?

      Yes, in that it would increase crop losses attributable to SO_2. However, we don't yet know how to estimate these losses.

   B. Estimates by other researchers have indicated the losses due to sulfur dioxide to be quite higher than your estimate. Why?

      Most SO_2 loss estimates would include data prior to tall stacks and when many smelters had poorer emission controls. Other researchers might be including estimates of interactive effects with other pollutants.

Pollution Resistant Plants

5. On page 7 you indicate one of the best srategies to combat the effects of air pollution is by breeding plants that are resistant to air pollution stress.

   A. What research is being conducted to breed pollution resistant plants?

      Air pollutant stress is not an active part of any breeding program. We have a start in such a program working with a bean breeder in Virginia. Most current efforts are by farmers or by breeders in polluted areas who select resistance cultivars without understanding that air pollution is causing the effects. This has been done to some extent for tobacco, bean and potatoe.

   B. Will these plants be commercially available in the near future?

      It would take 5 to 10 years to develop a viable breeding program with tested and acceptable cultivars.

ANSWERS TO QUESTIONS—DR. PAGE

P.O. Box 87
North Hero, VT 05474
August 5, 1981

James H. Scheuer and George E. Brown, Jr.
U.S. House of Representatives
Rayburn House Office Building
Washington, D.C. 20515

Dear Representatives Scheuer and Brown;

First, let me thank you for your kind invitation dated June 17, 1981, to provide testimony before a joint hearing devoted to the question of agricultural damages from airborne residuals. I hope that you found my written and oral testimony of assistance to you and your colleagues as you deliberate on Clean Air Act revisions. It is my view that secondary standards are very important to the welfare of U.S. citizens and we are only beginning to understand the significance of agricultural damages related to airborne residuals.

Following my testimony of July 9th, Dr. Greene handed me two pages of questions concerning my written and oral testimony. I am sending my responses to both of you.

The first question related to the region chosen for the Ohio River Basin Energy Study (ORBES). There were three parts to the question. Part A requested an explanation for the regional boundaries selected in the study; Part B, whether or not results could be generalized to other regions in the United States; and Part C questioned the exclusion of those portions of the states near the Great Lakes. The ORBES project covered a three year period: Phase 1 spanned the first year and Phase 2 the second two years of the study. The regional boundaries in Phase 1 did not include Pennsylvania and West Virginia; Phase 2 boundaries included most of West Virginia and the western portion of Pennsylvania. I joined the project when Phase 2 was just starting and after decisions had been made concerning Phase 2 boundaries. I am not in a position, therefore, to comment on the selection of Phase 2 boundaries. It was my impression that the boundaries were chosen so as to include most of the Ohio River Drainage Basin (Tennessee was excluded because of problems dealing with TVA as a utility), to exclude the northern tier of counties in the basin that bordered on the Great Lakes because of difficulties in handling water-related problems in the Great Lakes, and so as to include all of the Eastern Interior coal fields and most of the Appalachian coal fields. It is my view that the study region does represent a unique area within the contiguous fourty-eight states and the regional boundaries were probably drawn as well as could be done given the nature of the impact assessment which was to be performed. With respect to whether or not study results could be applied to other regions of the country, the results which I reported to you on July 9th probably cannot be generalized. There are several reasons for this, not the least of which is the regional variation in air quality, the different sensitivities of the same crop to airborne residuals as a function of soil conditions, moisture conditions, sunlight conditions, etc. as well as the regional nature of agricultural markets which influence competitive prices for agricultural goods. I believe an accurate assessment of damages to the agricultural sector on a national scale should be conducted using a set of regional studies, each employing an identical methodology, and then summed for a national total. As to the third part of the question, it is my understanding that the counties bordering on the Great Lakes were excluded in order not to confound the water quality question related to the main tributaries in the Ohio Basin.

The second question concerned error bounds in the sequence of research results leading to monetarized agricultural damages. The two parts to the question are as follows: Why are the error bounds unknown?; generally, what type of errors are they?

The error bounds on most of the research results leading to monetarized agricultural damages are largely unknown because sample sizes are not sufficiently large to yield statistical significance. Another way to view the matter is to observe that results at each stage in the project could be biased upward or downward, the direction of bias being unknown because sample size is not sufficient to employ statistical tests of significance. It is my view that the results represent state-of-the-art modeling in conjunction with existing data bases. Most of the errors (the second part of the question) would tend to be related to biased samples. As an illustration, it is well known that measurement of concentrations most anywhere in the country tend to be biased because of the location of monitoring devices (generally in urban areas at elevated levels). Because this is the case, one is really not comfortable with the notion that these measurements may be extrapolated on a region-wide basis. It seems to me, then, that in almost any phase of this type research (measurement of ambient air quality, estimation of physical crop losses, or monetarizing such losses) results could be substantially improved by better data bases in order that research might reflect appropriate and significant statistical information.

The next question is a very general one and asks whether or not it is possible to accurately estimate direct losses to agricultural producers over a twenty-four year period and is it realistic to assume that one can predict agricultural prices out to the year 2000. It is a very important question and one which raises the issue as to whether or not my results reported on July 9th should be believed . It would take a very large number of pages to provide a proper answer to this question. Suffice to say that in terms of economic theory, the direct loss estimates presented during my testimony are correct. Most significant research addressing monetarized agricultural losses from airborne residuals has used the same theoretical structure as that which formed the bases of my own research. As to the question of predicting agricultural prices for a twenty-four year period in the future, it is my view that one cannot do that. Because that is the case, I choose to use a constant real price for the three crops involved in the region out to the year 2000. This tends to have the effect of underestimating the direct losses so that if we are in error, we are in error on the conservative side. Such an approach, it seems to me, better protects one against critics than a more elaborate procedure that tries to actually predict prices.

The next question relates to the three crops used in the study (corn, soybeans, and wheat) and in particular whether these crops are sensitive to ozone (O_3) and SO_2 concentrations and would the results be different if other crops had been examined. As noted in my testimony, the question of physical damages is one dealt with by The Institute of Ecology (TIE) and I relied on their judgement as to the sensitivity of these crops to the two pollutants under investigation. The materials in the TIE report certainly suggest that the crops are sensitive to O_3 and SO_2. As to whether or not other crops should have been considered, again that is really a question better responded to by staff members at TIE. It is my understanding that in their judgement these crops were the ones where the greatest amount of information was available as to potential damage and where reasonable coefficients could be constructed relating physical damage to concentrations of pollutants. Further, within the ORBES region, most commercial agriculture is concentrated in corn and soybean production. In any event, the proper answer to this question should come from Dr. Orie Loucks or members of his staff at TIE.

The next question relates to the selection of pollutants used in the study, namely SO_2 and O_3. The first part of the question is what effect would the use of other pollutants have on the study results. I am not in a position to answer that question as it relates to physical dose-response relationships between pollutants and crops. Again, staff members at TIE should be in a position to answer that question. The second part of the question, would acid rain have made a significant impact, is a particularly important question. I believe the attitude of TIE was that the evidence on the dose-response relationship between acid rain and crops was not sufficiently well developed at that time to justify estimates of physical losses. Since the completion of the ORBES project, I believe further work has been conducted at TIE and it might be of considerable interest to subcommittee members to obtain results of that work. In any event, as I had no physical crop loss estimates associated with acid rain, I was unable to provide any economic estimates of the associated dollar losses. My understanding from those working in the general area of ecology is that acid rain may have a significant effect on commercial crops, be they agricultural or timber.

The last three questions all relate to my interpretation of research results: Greater attention should be given to revising SIP standards to include NO_x as a criterion pollutant (only one of the six states currently include NO_x as a criterion pollutant for SIP units) and to strengthening NO_x standards on NSPS and RNSPS units. There are three questions asked: First, what specific changes should be made; second, are NO_x emissions from point and mobile sources adequately addressed in the Clean Air Act; and third, what changes should be made in the Clean Air Act in this regard.

With respect to SIP, NSPS and RNSPS standards, changes should be based upon research documenting physical and monetary damages from O_3 (NO_x is the precursor). Adequate research on a region-by-region basis has not yet been conducted which would permit setting such standards. The response to the question, then, is really to procrastinate and point out that research should be carried out in order to define appropriate standards.

The second question relates to whether or not NO_x emissions are adequately addressed in the Clean Air Act. The answer is strongly in the negative. This is not necessarily a criticism of the Clean Air Act, as the Act concerned itself, for the most part, with primary standards. It is only in recent years that we have become aware of the kinds of economic costs to the recipients of pollutants from point or mobile sources far removed. The thrust of the testimony, then, is to suggest that the Clean Air Act in present form clearly does not place proper emphasis on secondary standards, and in particular NO_x emissions, and the relationship between such emissions and agricultural damages.

The changes which should be made in the Clean Air Act relate to the definition of criterion pollutants and to emission levels. With respect to agricultural damages, clearly NO_x is a major criterion pollutant and permissable emission levels in order to achieve acceptable ambient air quality should be based upon research results with respect to agricultural and other damages. The necessary research for the promulgation of such standards has not yet been performed.

I hope you will find my responses to your questions satisfactory. I realize that it is difficult to convey the full implications of research in the context of written and oral testimony. Should you have further questions concerning my own research I hope you will feel free to contact me.

Again, I wish to thank you for the opportunity to provide testimony on this important question and I sincerely hope the information I provided will assist you in your deliberations on the Clean Air Act.

Sincerely,

Walter

Walter P. Page, Ph.D.

WPP/md